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REMOTE SENSING ANALYSIS OF

THE OIL SPILL DISPERSANT SEA TRIAL

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REMOTE SENSING ANALYSIS OF THE OIL SPILL DISPERSANT SEA TRIAL

by

Intera Environmental Consultants Limited
Ottawa, Ontario

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PREFACE

The oil-dispersant sea trials off Newfoundland in October 1981 were accompanied by numerous, airborne remote sensing sorties, executed by the Data Acquisition Division of the Canada Centre for Remote Sensing (CCRS). Subsequently, CCRS contracted Intera Environmental Consultants Ltd. (INTERA) to organize the large array of multi-sensor data sets into a comprehensive catalogue, and to perform initial data reduction and analysis on selected sub-sets of the data.

This report addresses the latter of these tasks under DSS Contract 5EZ.23413-1-1259. INTERA would like to thank Dr R.A. Neville, the Scientific Authority on this contract, for providing access to data and equipment, and for his support of our work. We are also grateful for the assistance provided by: S. Gill (Canadian Coast Guard [CCG]) and M. Fingas (Environmental Protection Service [EPS]).

G.J. Wessels
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1. INTRODUCTION

Of primary interest during the Newfoundland sea trials were the application and performance of the oil-spill dispersant, Corexit 9527. Two slicks were placed on the sea surface: a control slick and a test slick. Only the test slick was subjected to the dispersant. Various *in situ* measurements were taken at frequent intervals in both slicks. This procedure was conducted separately on 21 and 22 October 1981.

Overflights by the Canada Centre for Remote Sensing (CCRS) aircraft, C-GRSB, extended from before the time of dispersant application to several hours afterwards, and encompassed both test and control slicks. The C-GRSB was specially configured and instrumented for airborne remote sensing research. On these missions (CCRS Project Number 81-51) the active sensors were:

1. a multispectral scanner (MSS) with ultraviolet (UV) and thermal infrared (TIR) bands active;
2. a laser fluorosensor, which suffered from recording difficulties (no useful data were produced);
3. a low light level television (LLLTV), which was forward-looking at 45° and horizontally polarized;
4. a 70-mm camera, forward-looking at 45°, recording in the UV, and horizontally polarized;
5. a nadir-looking, 9 in camera with colour film;
6. an upward-looking sky radiance detector.

A full description of the missions, sensors and airborne data sets collected was presented in INTERA (1982).

2. MULTISPECTRAL SCANNER DATA REDUCTION

The MSS data were collected on 14-track, MINCOM high-density digital tapes (HDDT). The time code, UV and TIR were recorded on Tracks 1, 13 and 14 respectively, of the HDDTs AR0518 (21 October 1981) and AR0519 (22 October 1981). All data were S-bend corrected during flight, and collected at 50 scans per second. The analogue gains and offsets, however, were altered during the experiment. (Normal operating mode has a gain setting of 100. See Table 2.1 for analogue gains and offsets.)

The data were reformatted onto computer-compatible tapes (CCTs) in standard two-channel, Johnson Space Centre (JSC) format (UV on Channel 1; TIR on Channel 2) with the data from as many sequential flight lines as possible recorded on each CCT for economy of tapes. (See INTERA, 1982 for further information on MSS and a detailed catalogue of MSS data collected.)

2.1 WATER REFLECTANCE AND RADIANCE IN THE ULTRAVIOLET

Reflectance (R) may be defined as the ratio between the upwelling spectral radiance at the sensor N_λ^S and the downwelling spectral radiance N_{SKY}, i.e.,

$$R = N_\lambda^S / N_{SKY}$$

but

$$N_\lambda^S = \frac{S - D}{g_1 g_2 R_\lambda}$$

where S = recorded digital signal

D = gained dark offset

g_1 = digital gain

g_2 = analogue gain/100

R_λ = responsivity

Table 2.1. Analogue gains and offsets

Date	Flight Lines	Gain	Offset
October 21	1 - 15	900	400
	16 - 17	700	400
	18 - 33	700	465
	34 - 83	700	475
October 22	1 - 36	800	470
	37 - 47	1000	460
	48 - 49	1000	480
	50 - 52	1000	445
	53 - 56	910	440
	57 - 60	1000	510
	61 - 66	900	435
	67 - 70	1000	490
	71 - 96	900	435

Data have been collected at various altitudes, and a linear best-fit between reflectance and altitude can be established for each day. Once the reflectance at zero altitude and the downwelling radiance are known, the water radiance at the sensor can be determined.

In an attempt to stretch the data over the widest possible range, the analogue gains and offsets have been altered between various flight lines (see Table 2.1). As a result, many flight lines have negative dark offsets that are recorded as zeros. Table 2.2 gives a listing of flight lines and the percentage of dark offsets recorded as zero (taken over a 3 sec interval). If these values are assumed to have a Gaussian distribution, a corrected average dark offset can be calculated for flight lines containing a significant number of dark "zero" offsets (see Figures 2.3 and 2.4).

With existing software, the recorded digital values and dark offset values have been extracted for a window of 30 pixels by 100 lines, centred on nadir over open water. The resulting data are shown in Tables 2.3 and 2.4.

The correlation between altitude and R for 21 October and 22 October is .9847 and .9078 respectively. With a linear best-fit, the water reflectance at zero altitude is .0456 for 21 October and .0428 for 22 October (see Figures 2.1 and 2.2). This reflectance includes surface and volume reflectance components. Solar and sky irradiance contribute to the volume reflectance of the upwelling radiance from water. The upwelling water radiance at the sensor N^S, however, may be calculated to a first-order approximation by multiplying the downwelling radiance by the reflectance at zero altitude. Errors occur at higher altitudes because of the small decrease in downwelling radiance, due to the thinner atmospheric layer. This variation, however, is small (see Section 4). This radiance calculation does not include the atmosphere-scattered contribution to the total.

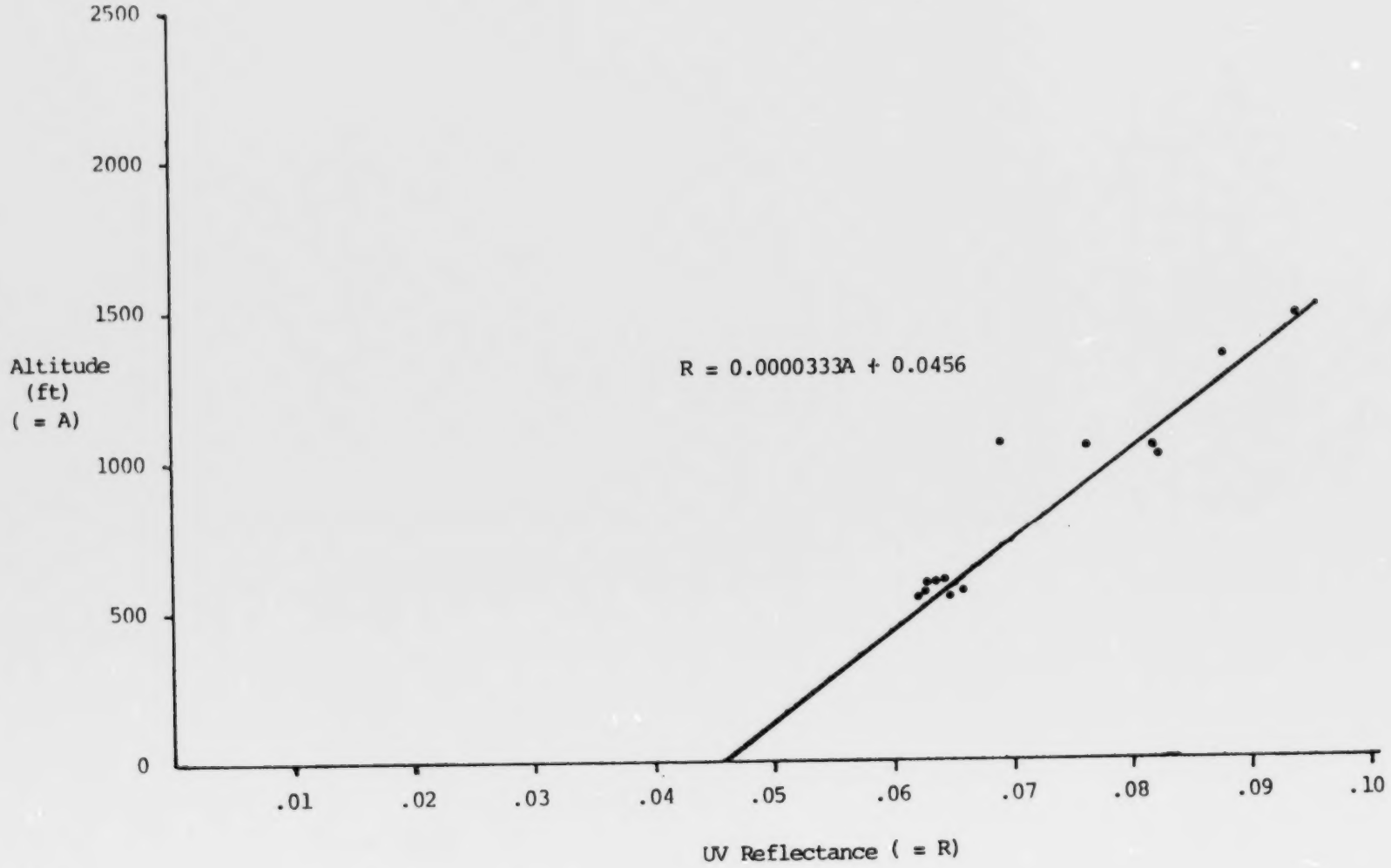

Figure 2.1. Altitude versus UV reflectance, 21 October 1981

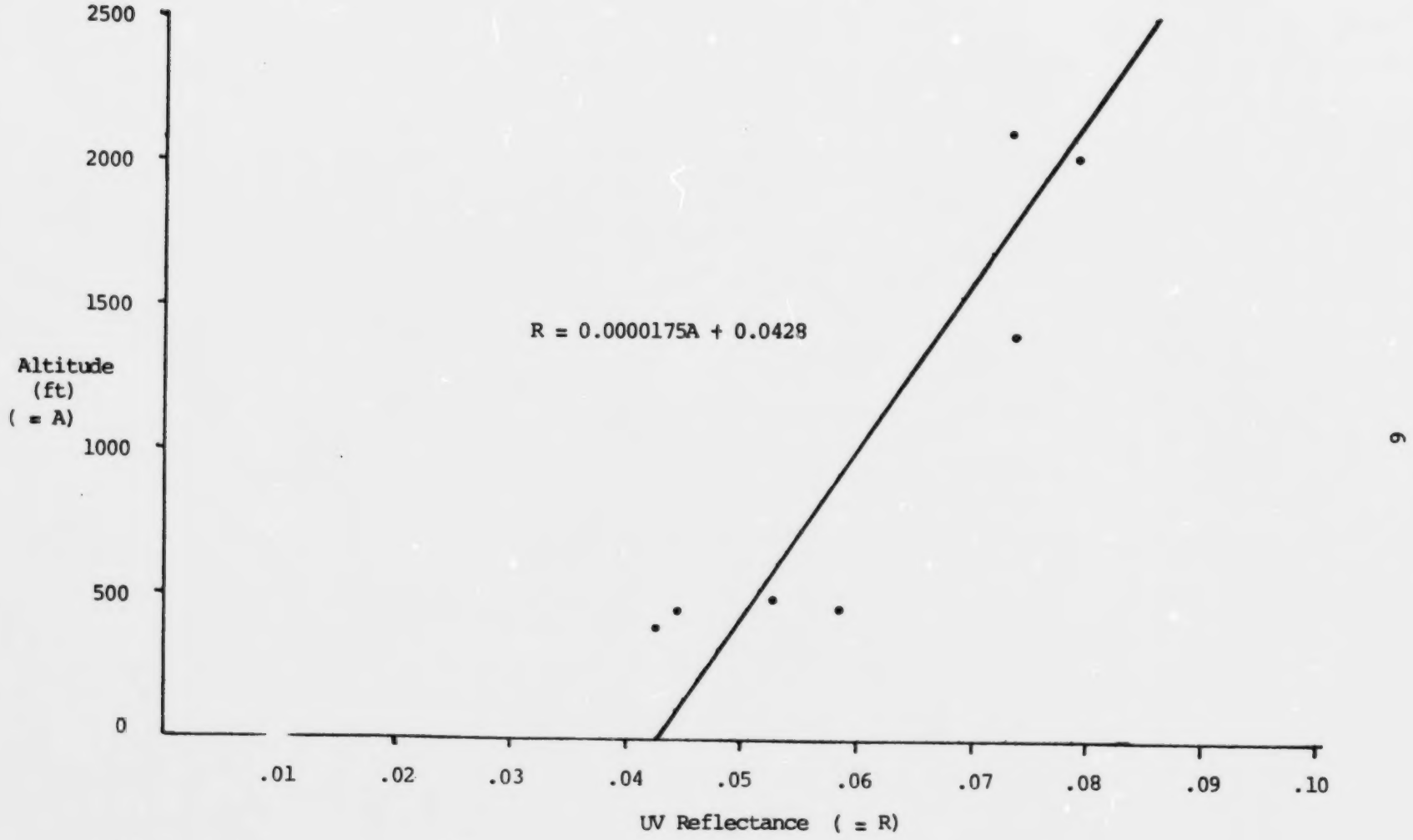

Figure 2.2. Altitude versus UV reflectance, 22 October 1981

Table 2.2. Percentage of UV dark offsets recorded as zero

Date	Flight Line	Percentage
21 October	1	70
	2	77
	3	85
	4	73
	5	60
	6	64
	7	67
	8	64
	9	67
	10	78
	11	68
	12	68
	13	74
	14	67
	15	52
	19	77
	20	69
	21	79
	22	84
	23	80
	24	76
	25	77
	26	79
	27	74
	28	78
	29	77
	30	79
	32	16
	34	29
	35	78
	36	85
	37	85
	38	85
	39	83
	41	83
	42	93
	44	50
	45	77
	46	87
	47	100
	48	100

continued . . .

Table 2.2. Continued.

Date	Flight Line	Percentage
21 October	49	100
	50	100
	51	100
	52	100
	54	0
	55	1
	56	0
	57	3
	58	2
	59	1
	61	2
	62	1
	63	0
	66	0
	67	0
	68	3
	69	7
	70	87
	71	51
	72	55
	73	47
	74	57
	75	20
	76	17
	77	17
	78	17
	79	27
	81	100
	82	100
	83	100

continued . . .

Table 2.2. Continued.

Date	Flight Line	Percentage
22 October	1	63
	2	53
	3	25
	4	10
	5	6
	6	6
	7	2
	8	2
	9	5
	10	5
	11	47
	12	42
	13	58
	14	88
	15	74
	16	74
	17	68
	18	68
	19	84
	20	86
	21	89
	22	84
	23	93
	24	90
	25	68
	26	48
	27	50
	28	49
	29	56
	30	54
	31	59
	32	54
	33	100
	34	100
	35	94
	37	70
	38	0
	40	92
	41	84
	42	89

continued . . .

Table 2.2. Continued.

Date	Flight Line	Percentage
22 October	43	87
	44	91
	45	83
	46	91
	47	96
	48	0
	49	0
	50	100
	51	100
	52	100
	53	100
	54	100
	55	100
	57	0
	58	0
	59	0
	60	0
	61	100
	62	100
	63	100
	64	100
	65	100
	66	100
	67	0
	68	1
	69	0
	70	0
	71	100
	72	100
	73	100
	74	100
	75	0
	77	0
	78	0
	79	0
	80	0
	81	0
	82	0
	83	0
	84	0

continued . . .

Table 2.2. Concluded.

Date	Flight Line	Percentage
22 October	85	0
	86	0
	87	0
	88	0
	89	0
	91	0
	92	0
	93	0
	94	0
	95	0
	96	0

Table 2.3. Calculation of R for 21 October 1981

$R_\lambda = 6.8 \times 10^6$ Wcm^{-2}sr^{-1}nm^{-1}

Flight Line	Altitude (ft)	S	Corrected Dark Offset	g_1	g_2	N_{SKY} (x 10^{-6}) Wcm^{-2}sr^{-1}nm^{-1}	R
56	555	148.25	40.62	4	7	8.50	.0665
57	570	142.24	36.98	4	7	8.41	.0657
58	560	148.36	47.12	4	7	8.45	.0629
59	540	148.18	44.16	4	7	8.36	.0654
62	570	152.37	52.37	4	7	8.36	.0631
63	570	150.95	49.27	4	7	8.41	.0635
66	580	147.85	46.41	4	7	8.32	.0640
67	550	143.96	46.47	4	7	8.23	.0622
68	590	147.38	43.74	4	7	8.23	.0661
72	1460	152.07	- 1.53	4	7	8.23	.0937
75	1230	151.19	15.57	4	7	8.09	.0880
76	1010	142.88	16.80	4	7	8.09	.0818
77	1030	142.43	18.00	4	7	8.05	.0812
78	1040	135.68	19.00	4	7	7.87	.0765
79	1050	133.01	13.60	4	7	7.91	.0793

Table 2.4. Calculation of R for 22 October 1981

$R_\lambda = 6.8 \times 10^6$ Wcm^{-2}sr^{-1}nm^{-1}

Flight Line	Altitude (ft)	S	Corrected Dark Offset	g_1	g_2	N_{SKY} (x 10^{-6}) Wcm^{-2}sr^{-1}nm^{-1}	R
38	1400	136.58	41.44	2	10	9.45	.0740
78	490	126.68	56.81	2	9	10.85	.0526
79	460	129.91	58.91	2	9	9.85	.0589
81	450	119.18	57.92	2	9	11.30	.0443
89	390	119.46	58.98	2	9	11.57	.0427
91	2010	145.03	47.55	2	9	10.08	.0790
93	2100	148.98	45.98	2	9	11.35	.0736

2.2 ULTRAVIOLET AND THERMAL INFRARED DATA CLUSTERING

To reduce the MSS data to discrete regions of oil radiance, the two-channel MSS data were classified into near-homogeneous regions of brightness, using a migrating-means classifier algorithm on the CCRS Image Analysis System (CIAS; see Gordon, 1978 and 1979.) The process involved generation of two-dimensional vectors and their grouping according to position in feature space.

In 16 chosen scenes, vector clusters were subdivided and combined to provide similar spectral regions within the oil slick. The spatial distributions of pixels corresponding to these vector clusters were colour-coded as "themes". The "speckled" noise of the themes was reduced by the multiple application of a nearest-neighbour theme filter. These radiometric manipulations were performed on sub-scenes of flight lines, which had been aspect-ratio corrected to present geometric fidelity (Table 2.5).

At 50 scans per second a scene is geometrically correct when:

$$L/P = (A \times .10475)/V$$

where L = number of MSS scan lines
P = number of pixels
A = altitude
V = velocity (see INTERA, 1982 for velocities and altitudes)

The colour-coded themes and the two-channel video sub-scenes are shown in the odd-numbered figures from Figure 2.3 to 2.33 (note that UV brightness is coded as red, and TIR as blue and green) and are stored on CCRS Tape BF0531 in Bell Northern Research (BNR) format. The thematic regimes in the oil are identified in terms of brightness (mean and standard deviation) and vector population in Tables 2.6 to 2.21 and the even-numbered figures from Figure 2.4 to 2.34. Note that the original CCT data of 8 bit (256 level) radiometric resolution are analysed in these tables and figures at 6 bit (64 level) resolution.

Table 2.5. MSS scan lines and pixels used in geometrically corrected scenes — 21 and 22 October 1981

Flight Line	Target	MSS Pixels	MSS Lines	Start Time (GMT)	Stop Time (GMT)
		21 October 1981			
22	Test	205 - 716	238 - 589	13:29:59.8	13:30:06.8
23	Test	53 - 716	441 - 895	13:35:26.8	13:35:35.9
24	Test	205 - 716	291 - 648	13:37:55.8	13:38:03.0
26	Test	15 - 716	496 - 978	13:42:43.0	13:42:52.6
37	Control	1 - 716	674 - 1136	14:18:43.5	14:18:52.7
68	Control	1 - 716	402 - 611	16:09:10.0	16:09:14.2
82	Control	257 - 716	681 - 1670	17:18:11.6	17:18:31.4
82	Test	257 - 716	1671 - 2660	17:18:31.4	17:18:51.2
		22 October 1981			
18	Test	202 - 713	1389 - 1690	13:09:25.8	13:09:31.8
19	Test	126 - 637	1763 - 2044	13:13:05.3	13:13:10.9
20	Test	205 - 716	348 - 640	13:15:27.0	13:15:32.8
23	Test	96 - 607	1532 - 1833	13:23:50.6	13:23:56.7
67	Control	28 - 716	1 - 707	15:49:55.0	15:50:09.1
74	Test	107 - 716	1 - 641	16:15:12.0	16:15:24.8
75	Control	1 - 716	570 - 727	16:19:56.4	16:19:59.5
87	Test	1 - 716	326 - 486	16:47:20.5	16:47:23.7

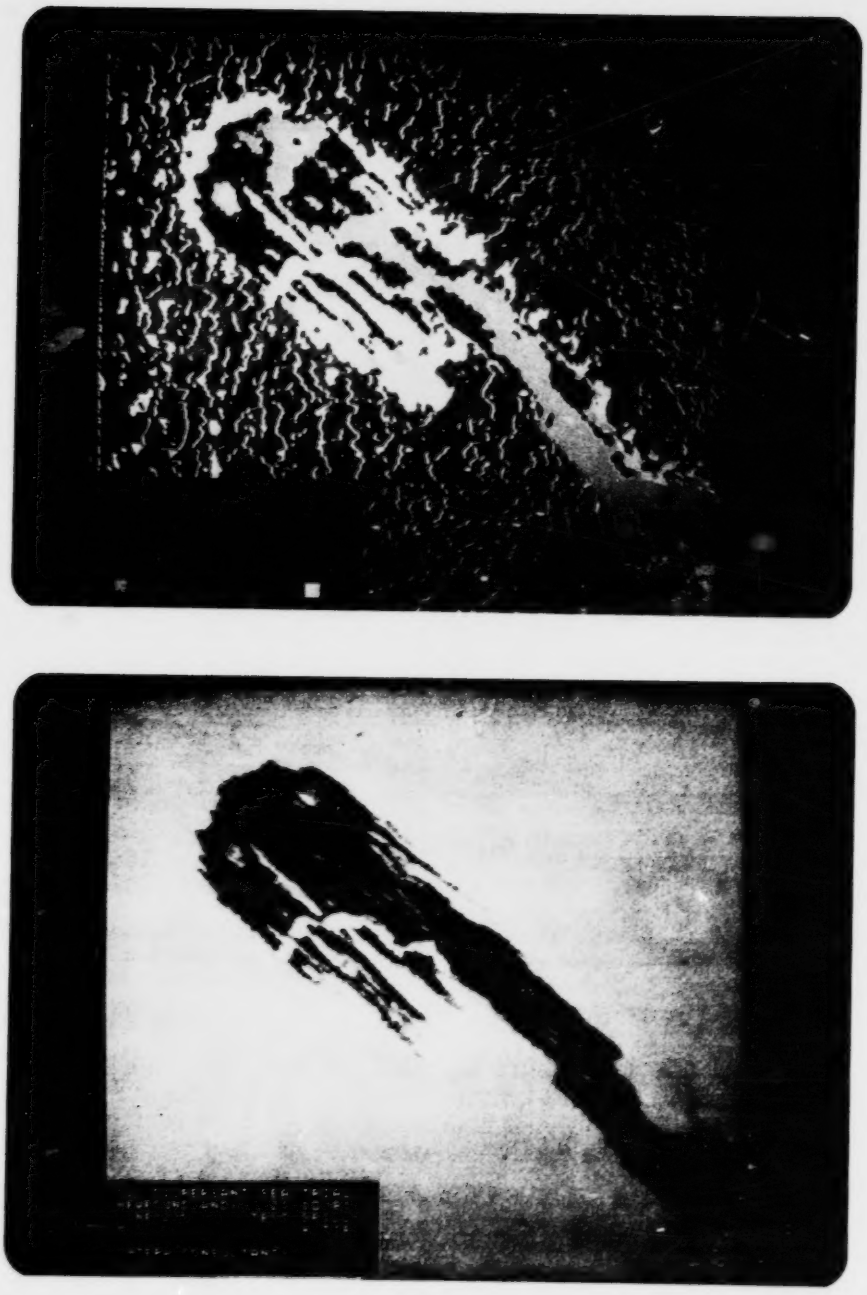

Figure 2.3. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 22 (test)

Table 2.6. Cluster means and standard deviations, 21 October 1981 — Line 22 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	33.2	21.5	3.95	3.68	270
2	39.2	15.6	4.14	3.76	364
3	25.8	35.1	2.51	0.96	124
4	32.6	35.1	1.93	1.07	83
5	39.8	34.5	2.84	2.43	244

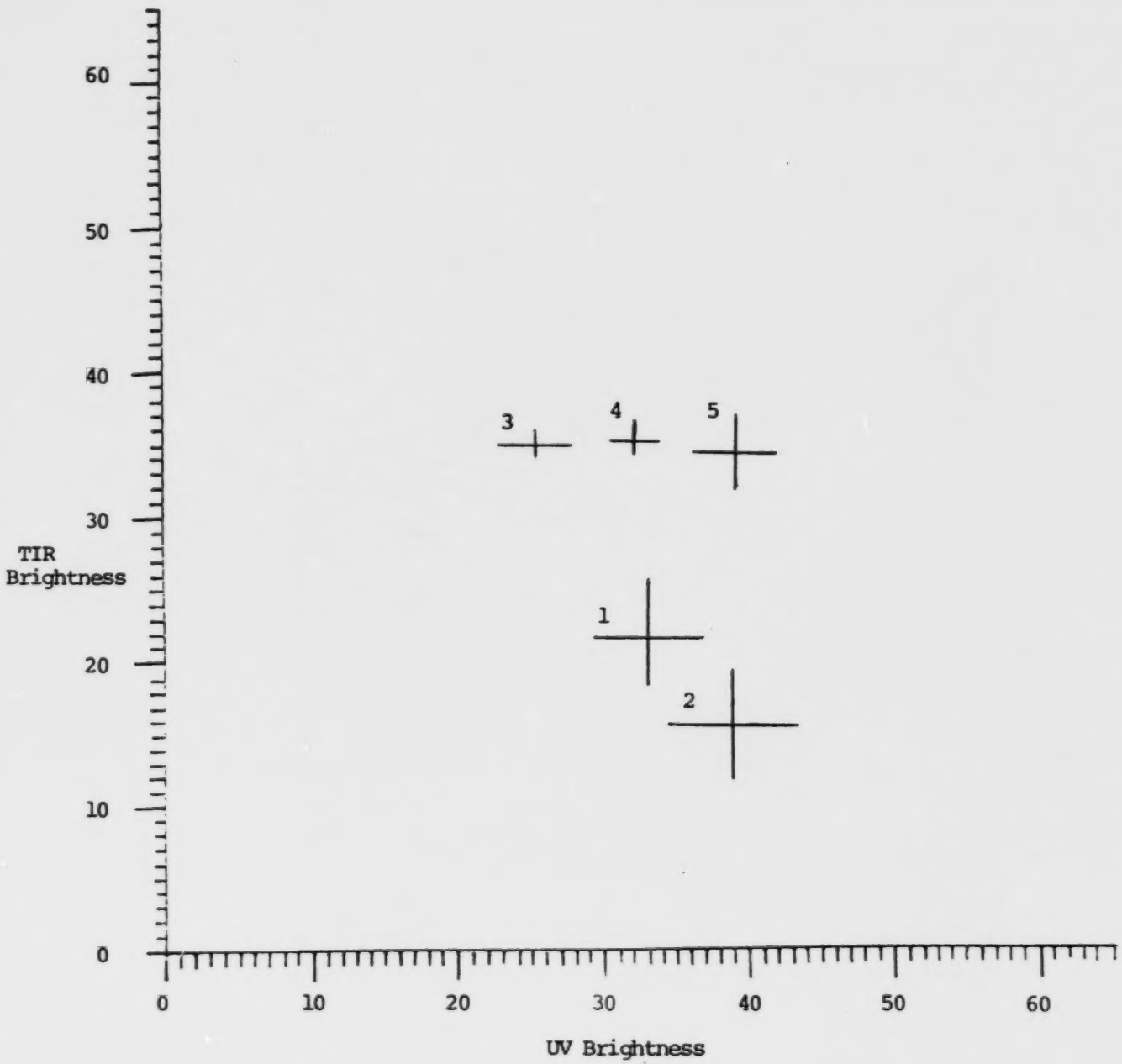

Figure 2.4. Cluster means and standard deviations, 21 October 1981, Line 22 (test)

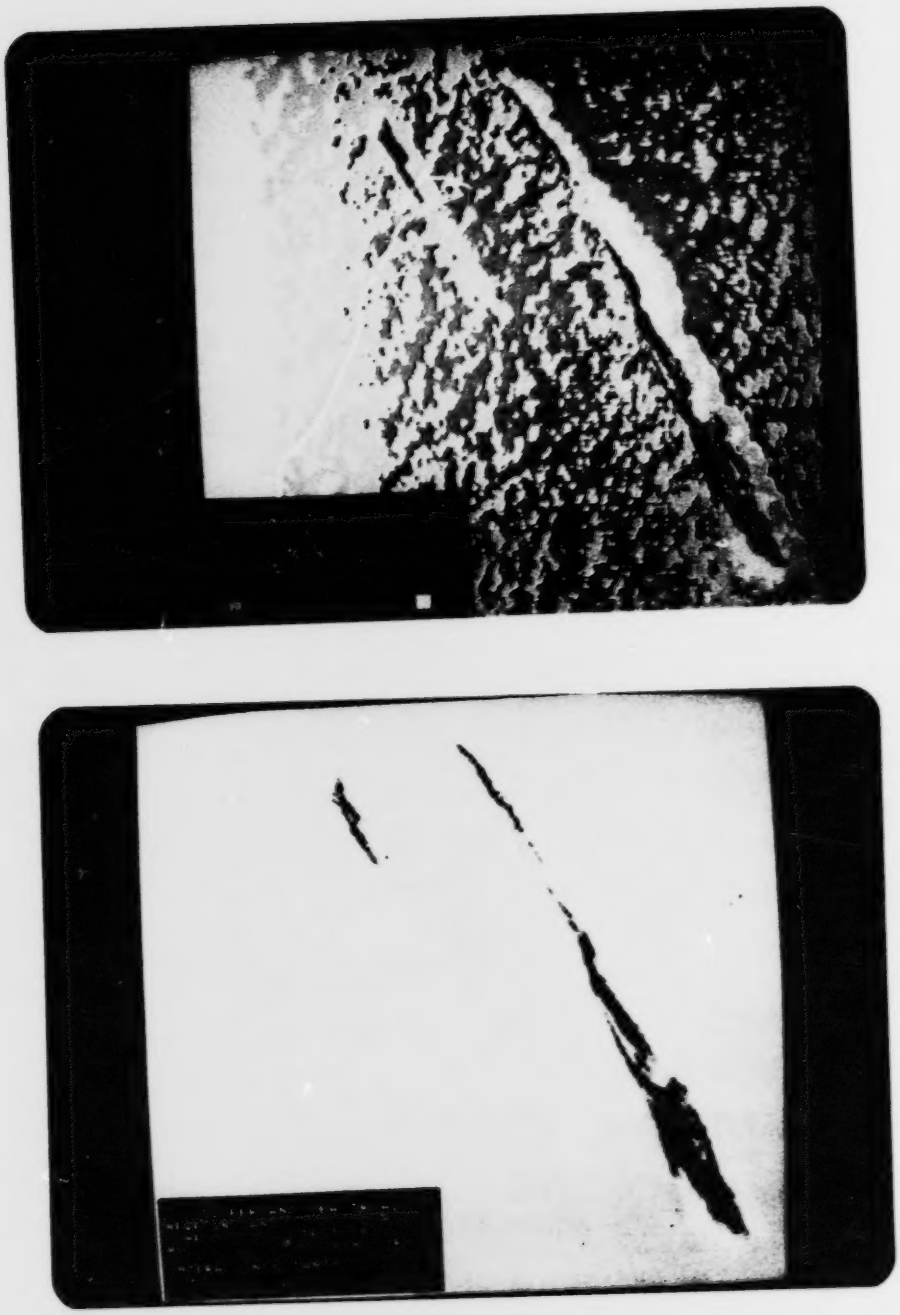

Figure 2.5. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 23 (test)

Table 2.7. Cluster means and standard deviations, 21 October 1981 — Line 23 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	32.7	40.3	1.97	0.00	118
2	30.6	22.8	3.28	4.66	283
3	38.8	25.1	3.26	4.68	257
4	25.8	40.3	2.70	0.00	165
5	41.1	40.4	3.62	1.21	214

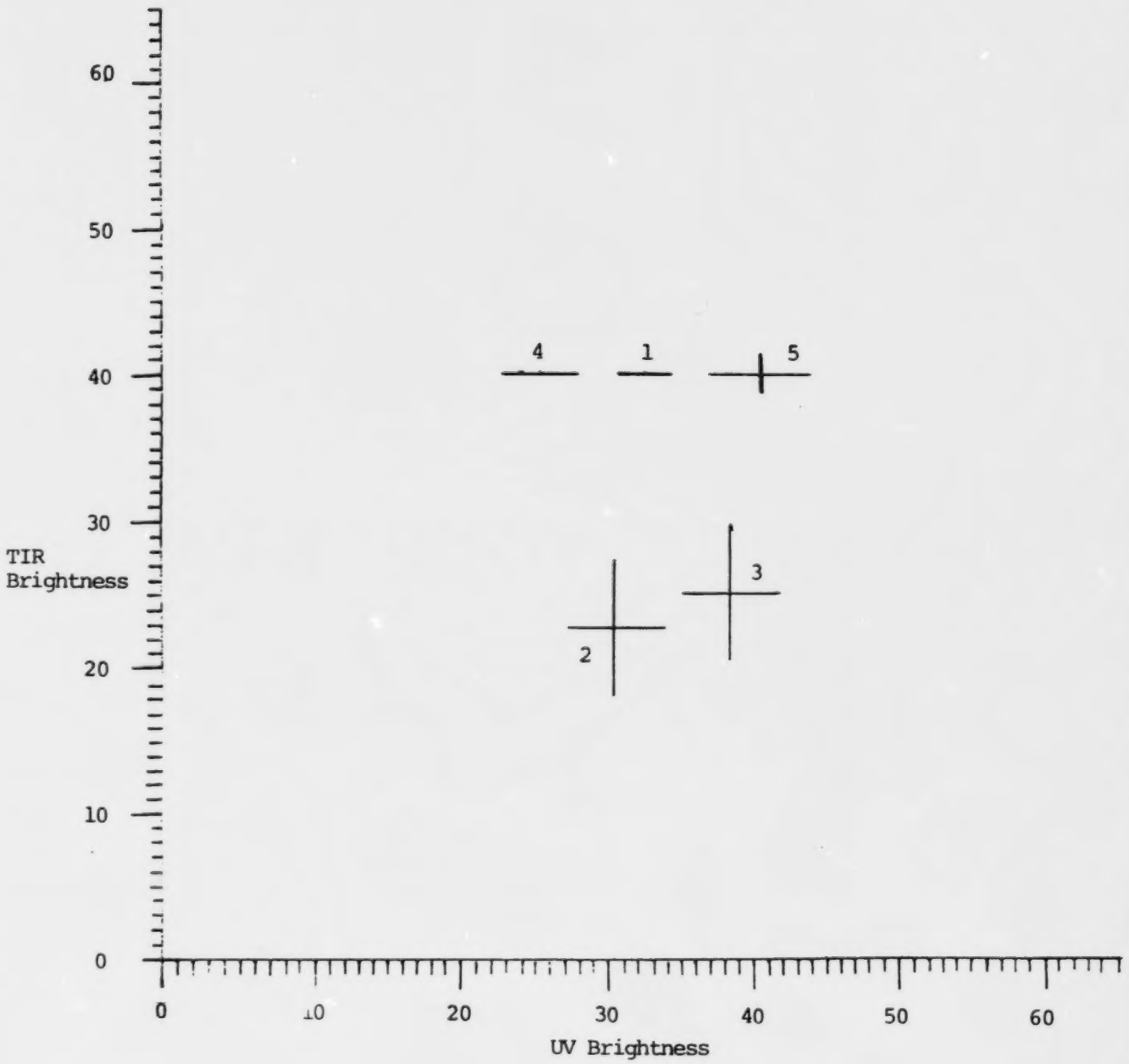

Figure 2.6. Cluster means and standard deviations, 21 October 1981, Line 23 (test)

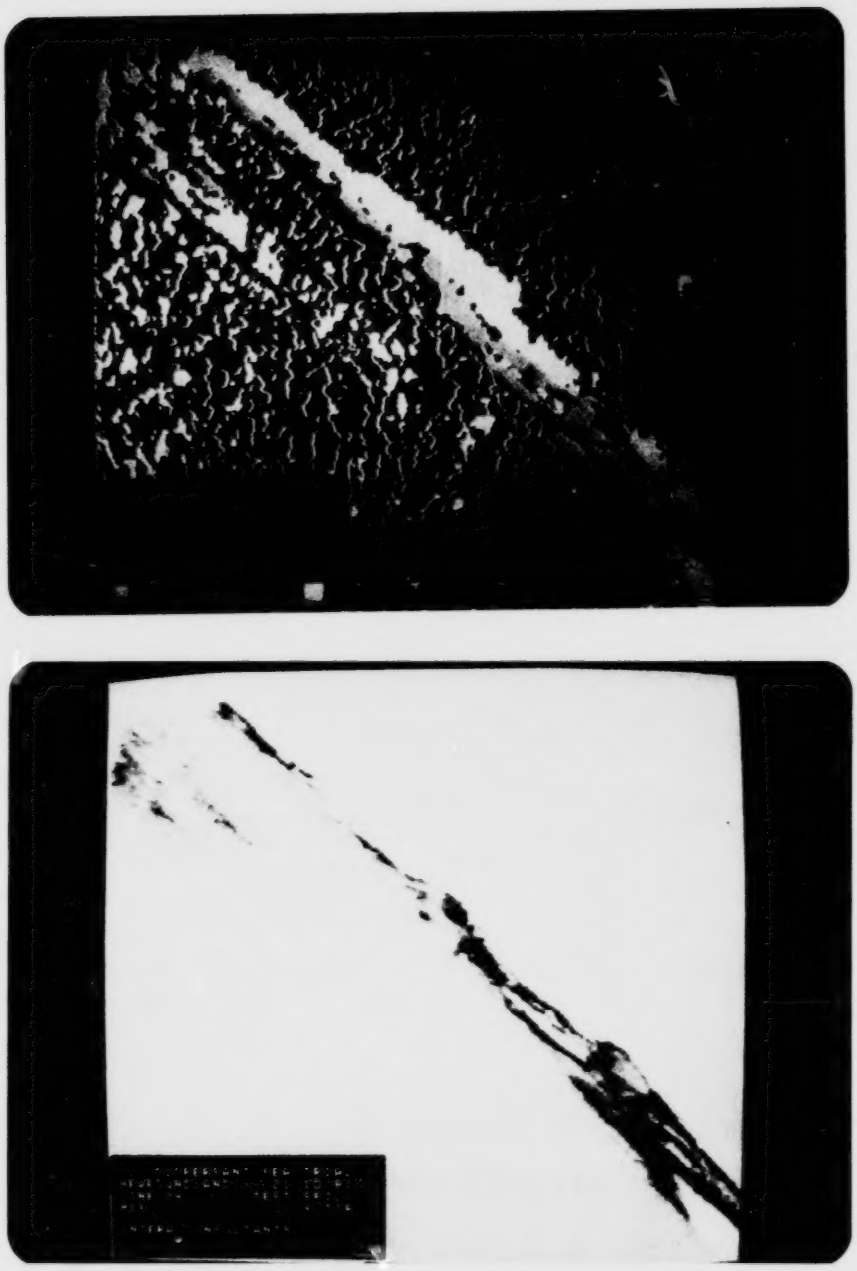

Figure 2.7. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 24 (test)

Table 2.8. Cluster means and standard deviations, 21 October 1981 — Line 24 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	35.5	24.2	5.19	3.31	385
2	35.1	33.6	3.94	2.43	146
3	26.2	41.5	2.27	0.00	145
4	32.7	41.5	1.94	0.00	83
5	39.9	41.2	2.79	1.97	213

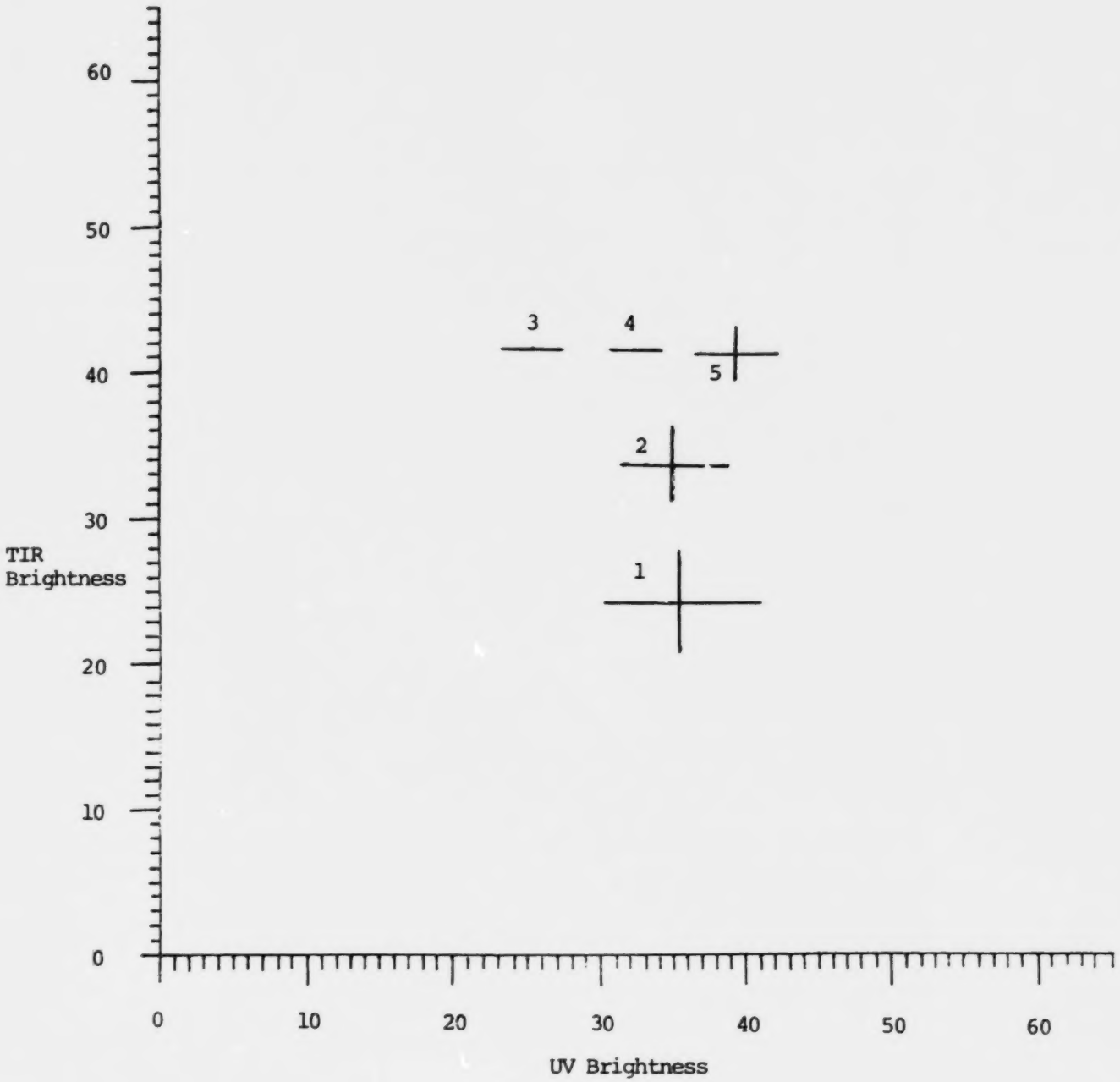

Figure 2.8. Cluster means and standard deviations, 21 October 1981, Line 24 (test)

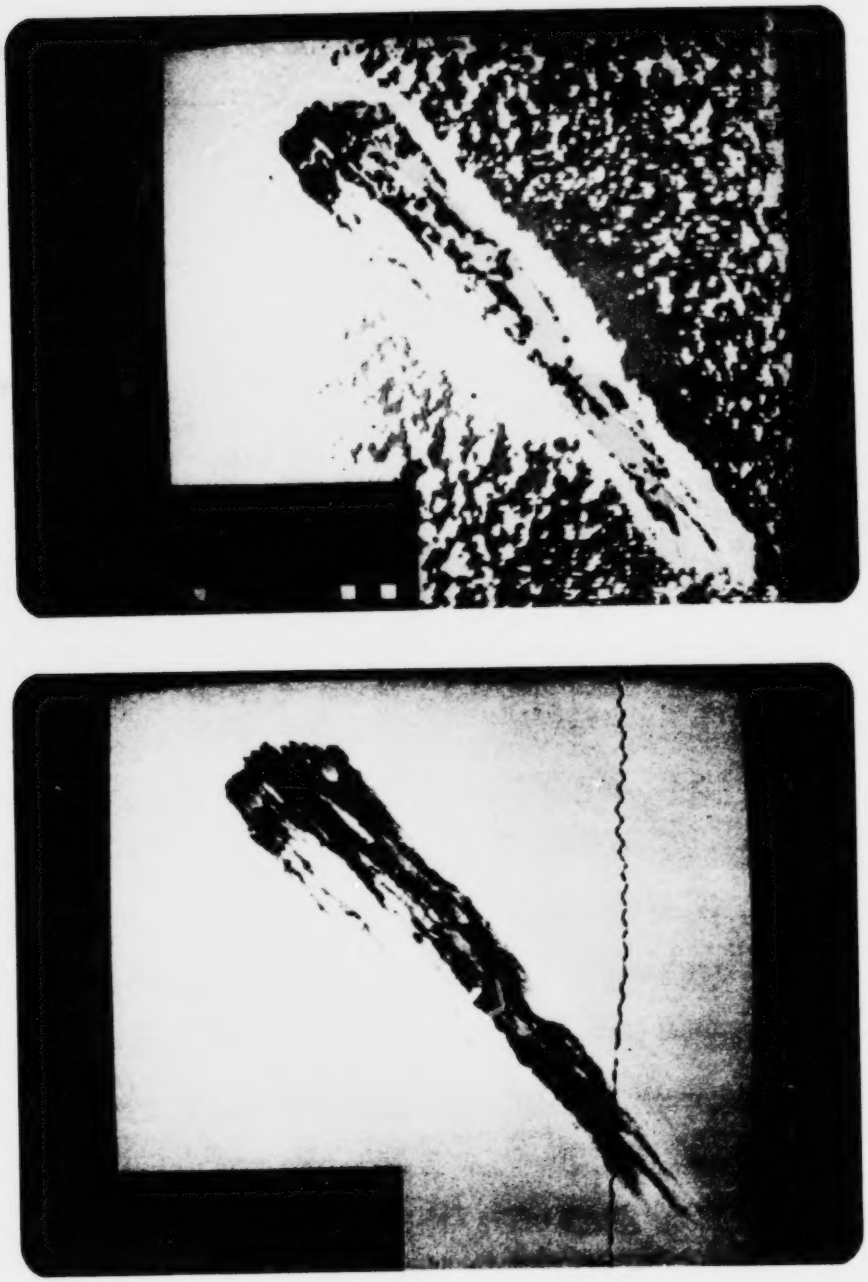

Figure 2.9. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 26 (test)

Table 2.9. Cluster means and standard deviations, 21 October 1981 — Line 26 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	35.2	22.5	3.56	3.43	268
2	45.9	22.6	3.60	3.56	279
3	39.9	30.0	3.36	2.56	113
4	27.6	40.2	2.59	1.12	178
5	35.3	40.2	2.27	0.00	124
6	44.5	39.7	3.71	1.32	215

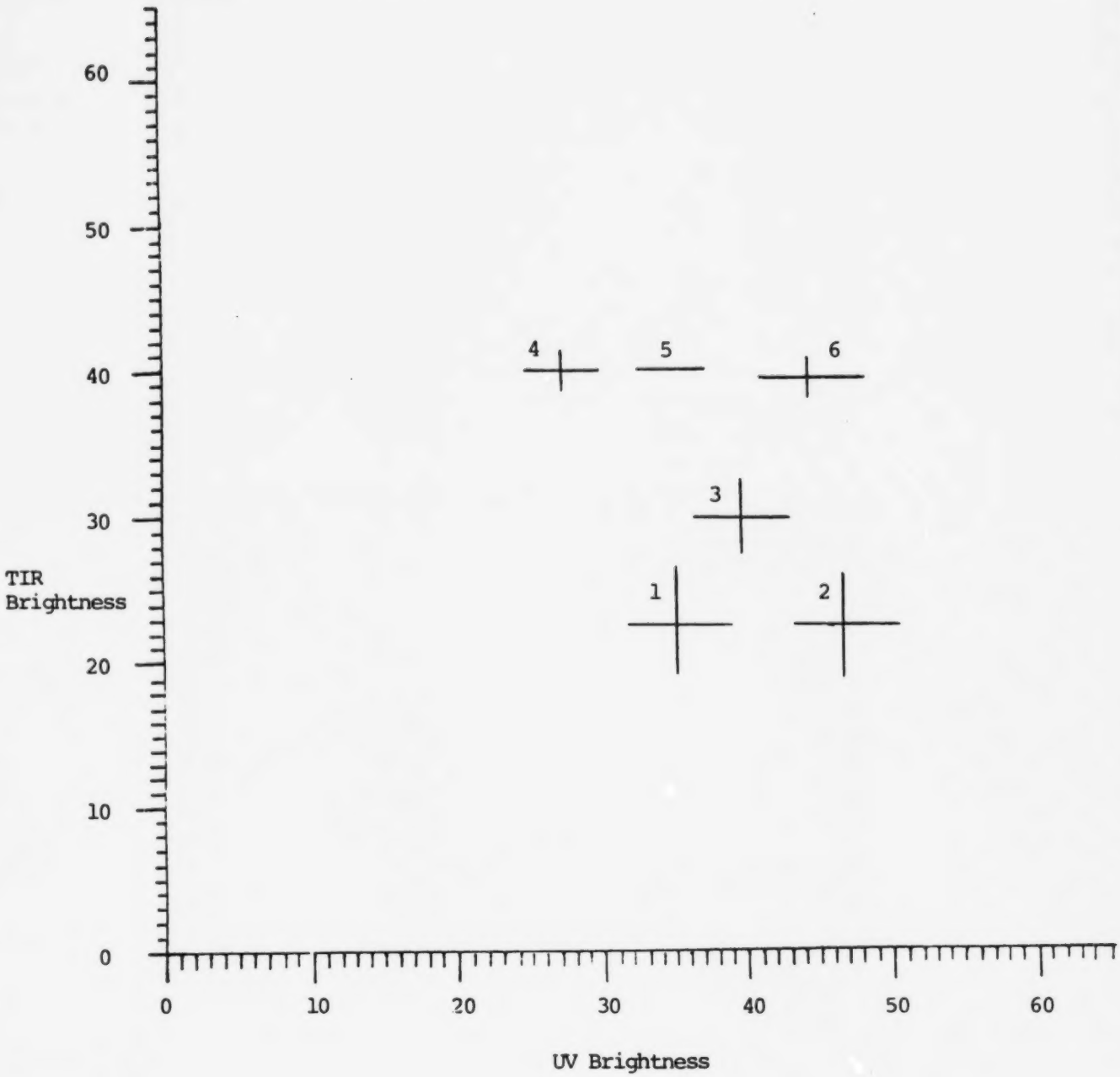

Figure 2.10. Cluster means and standard deviations, 21 October 1981, Line 26 (test)

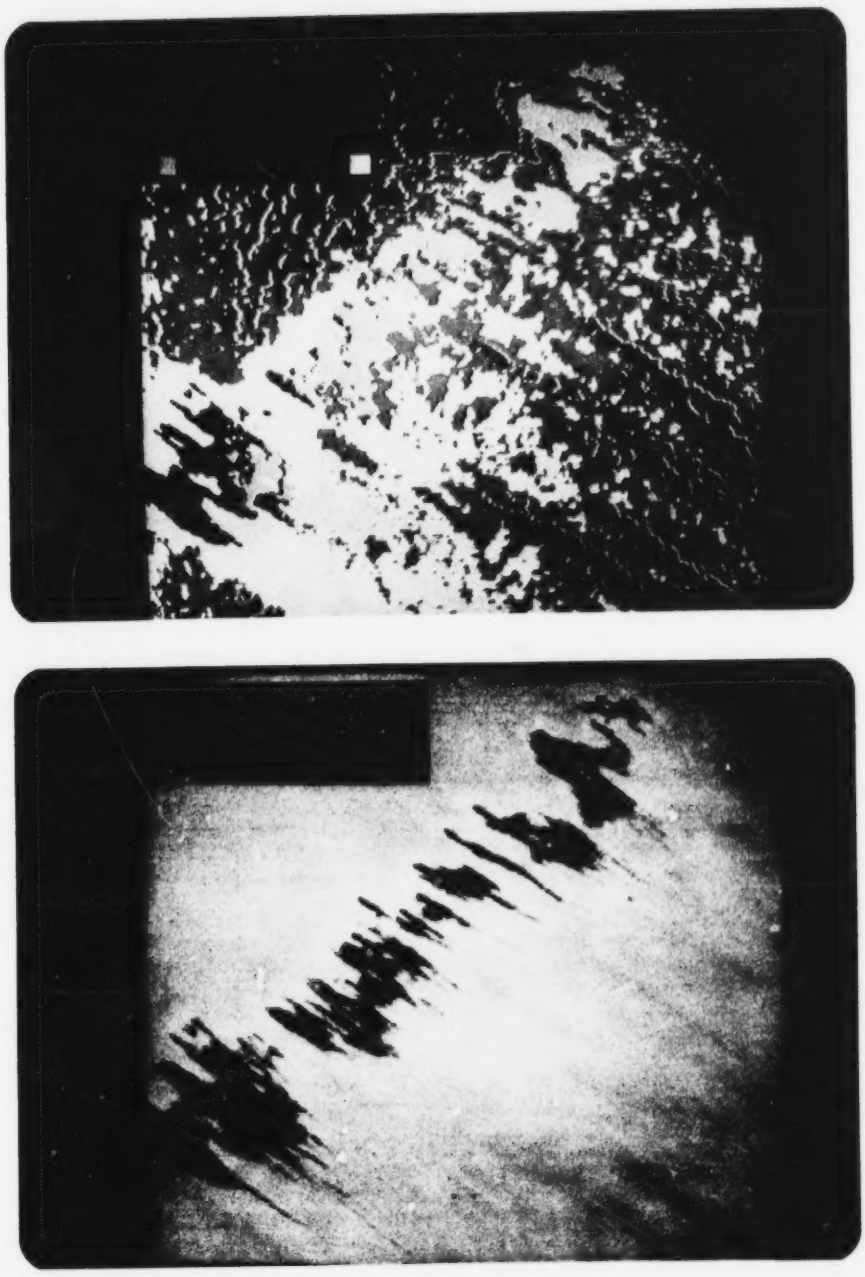

Figure 2.11. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 37 (control)

Table 2.10. Cluster means and standard deviations, 21 October 1981 — Line 37 (control)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	43.4	23.7	4.17	4.18	344
2	54.9	23.4	3.78	4.55	278
3	34.3	39.9	3.02	1.17	162
4	43.1	39.7	0.00	0.00	117
5	52.1	39.6	0.00	1.69	192

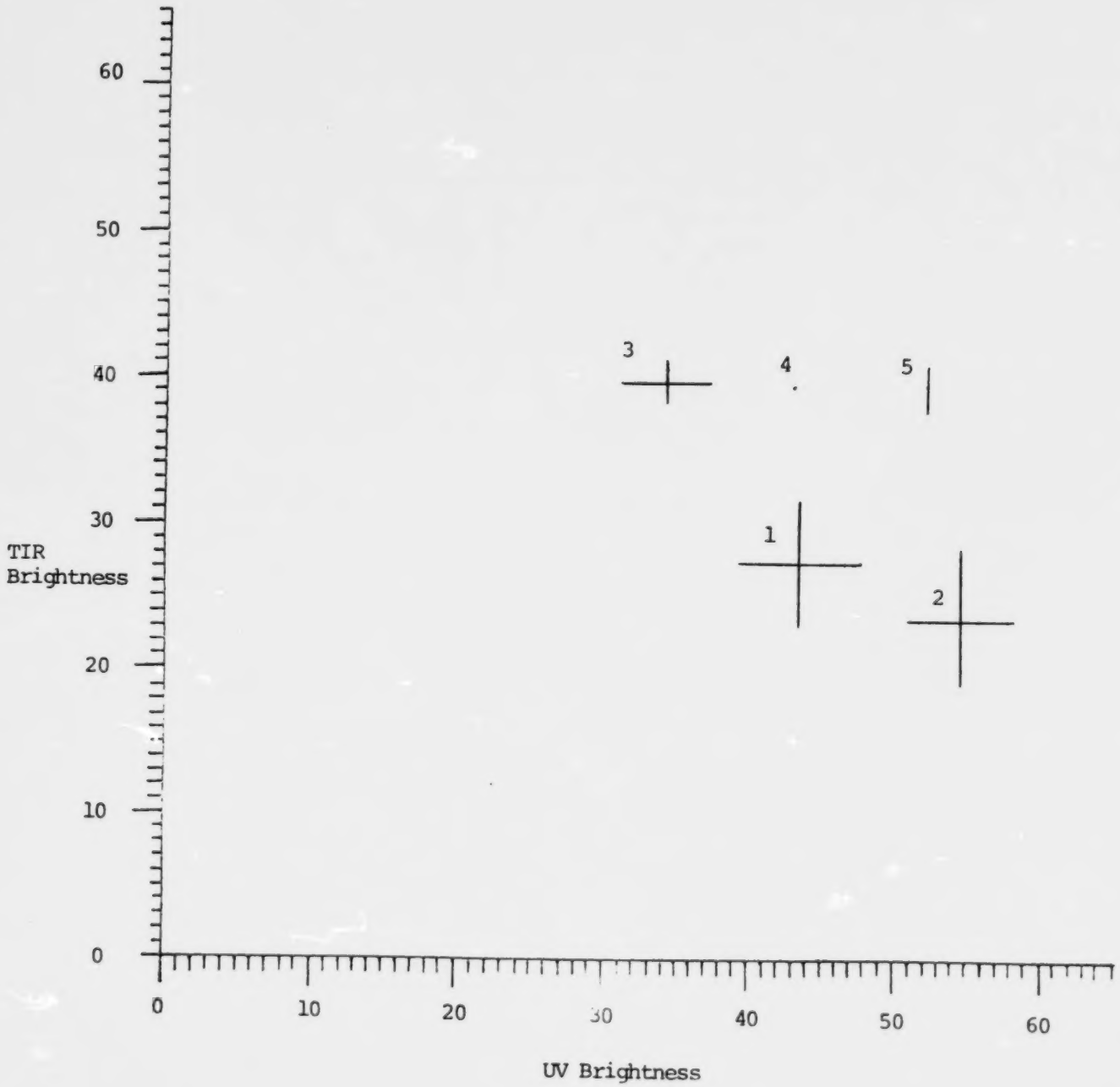

Figure 2.12. Cluster means and standard deviations, 21 October 1981, Line 37 (control)

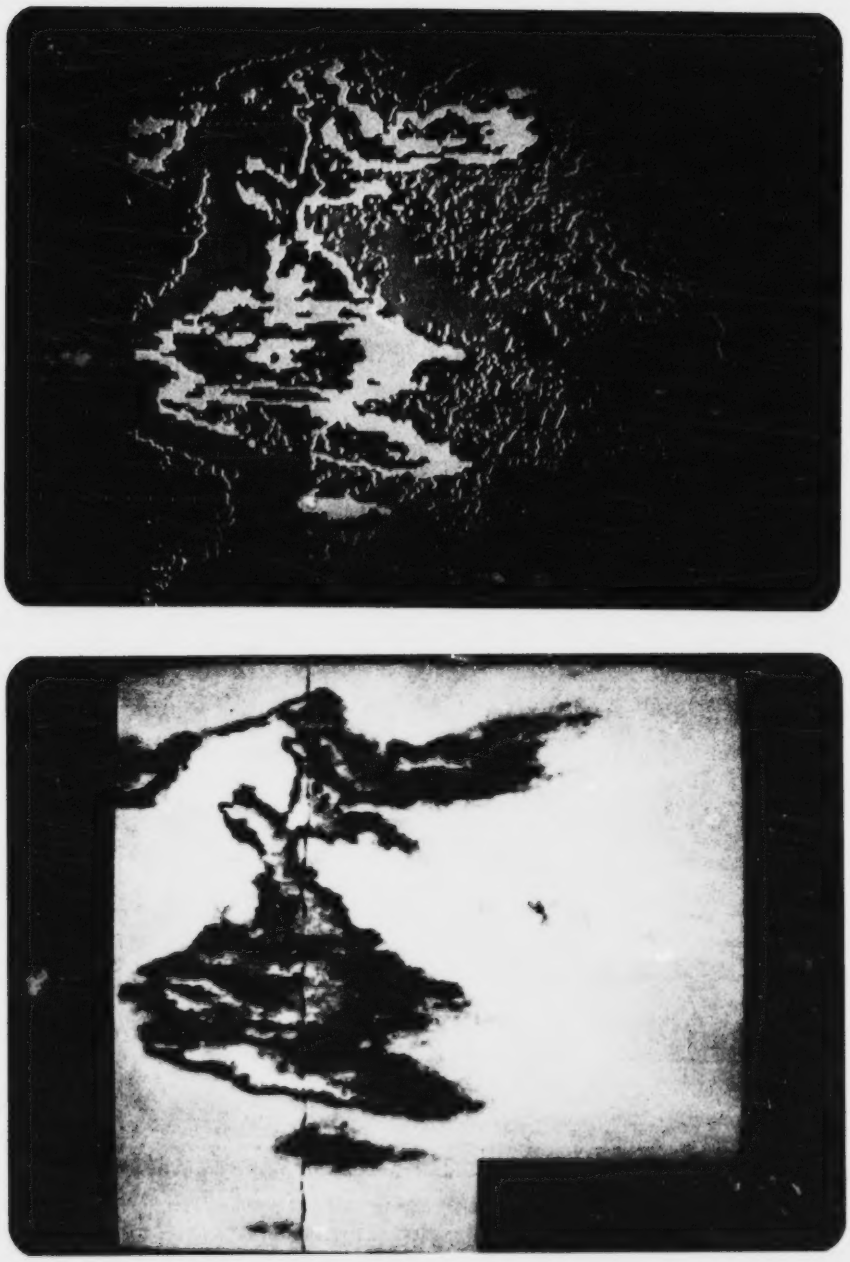

Figure 2.13. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 68 (control)

Table 2.11. Cluster means and standard deviations, 21 October 1981 — Line 68 (control)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	49.4	19.1	5.26	3.57	454
2	49.8	29.9	4.73	2.87	250
3	42.8	40.8	0.00	0.00	239
4	53.9	40.9	0.00	0.00	215

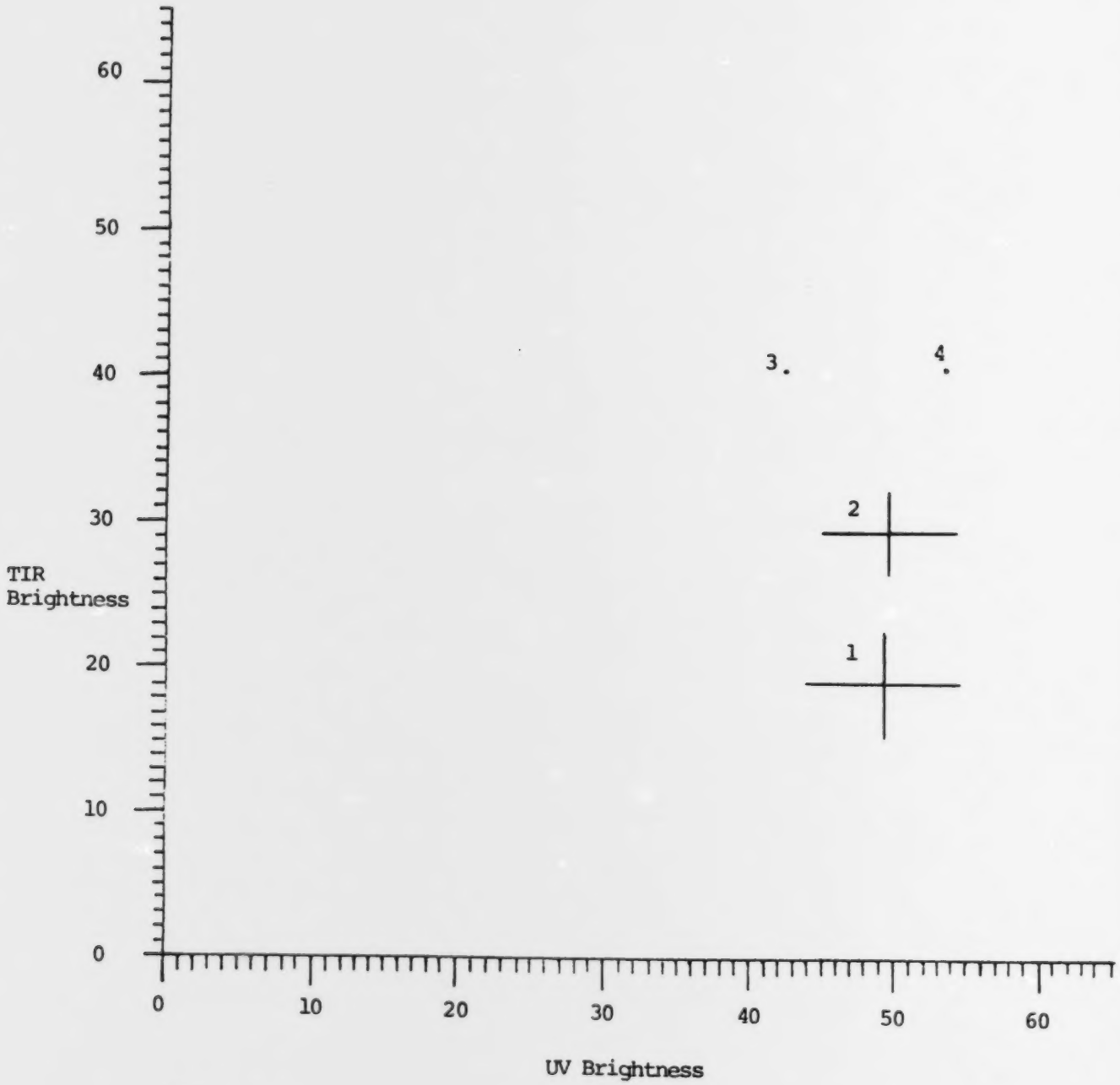

Figure 2.14. Cluster means and standard deviations, 21 October 1981, Line 68 (control)

Figure 2.15. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 82 (control)

Table 2.12. Cluster means and standard deviations, 21 October 1981 -- Line 82 (control)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	44.7	25.9	5.24	4.43	502
2	29.9	42.3	3.17	0.00	138
3	38.3	42.2	0.00	0.00	113
4	46.4	42.0	3.13	1.33	220

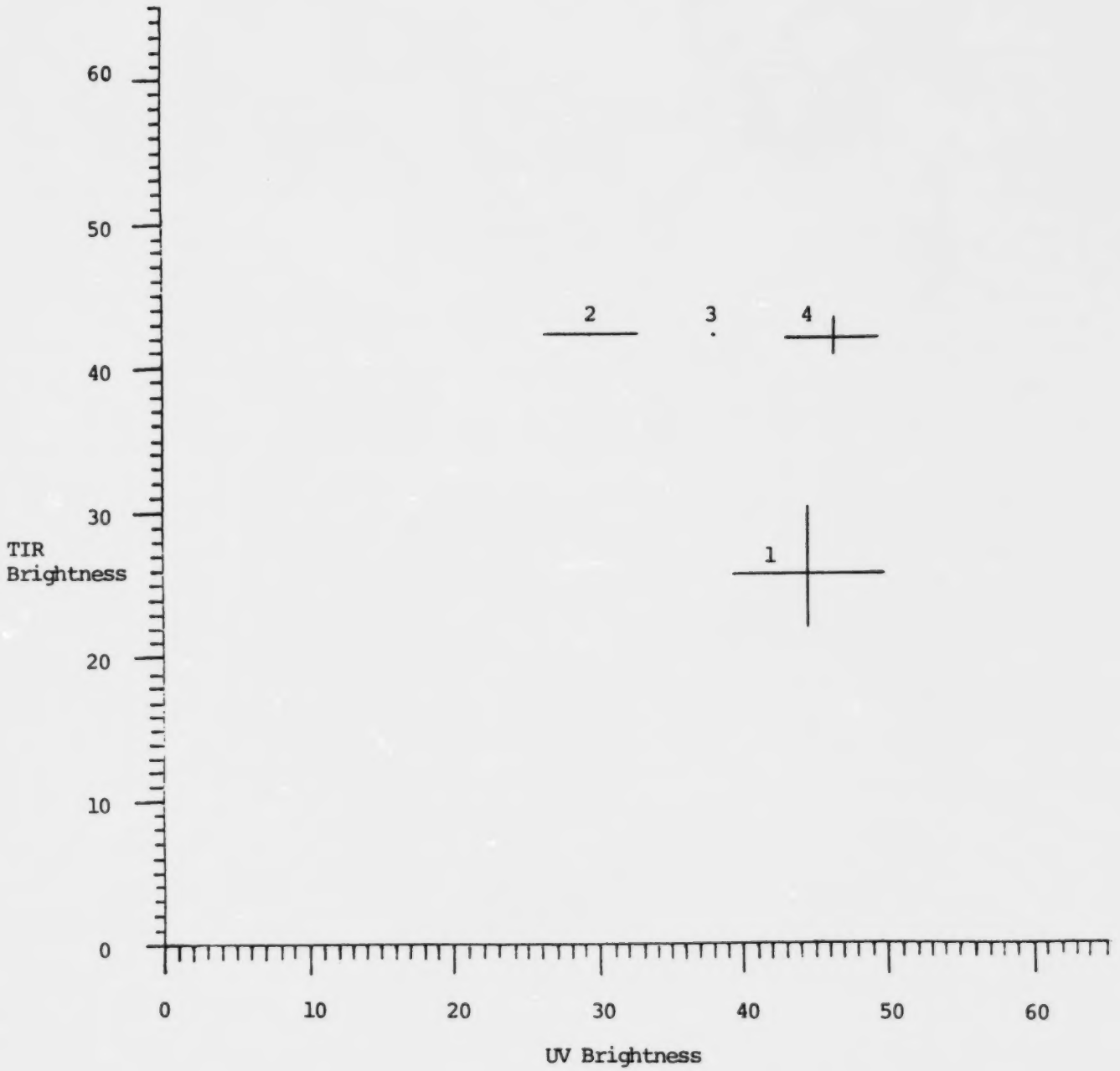

Figure 2.16. Cluster means and standard deviations, 21 October 1981, Line 82 (control)

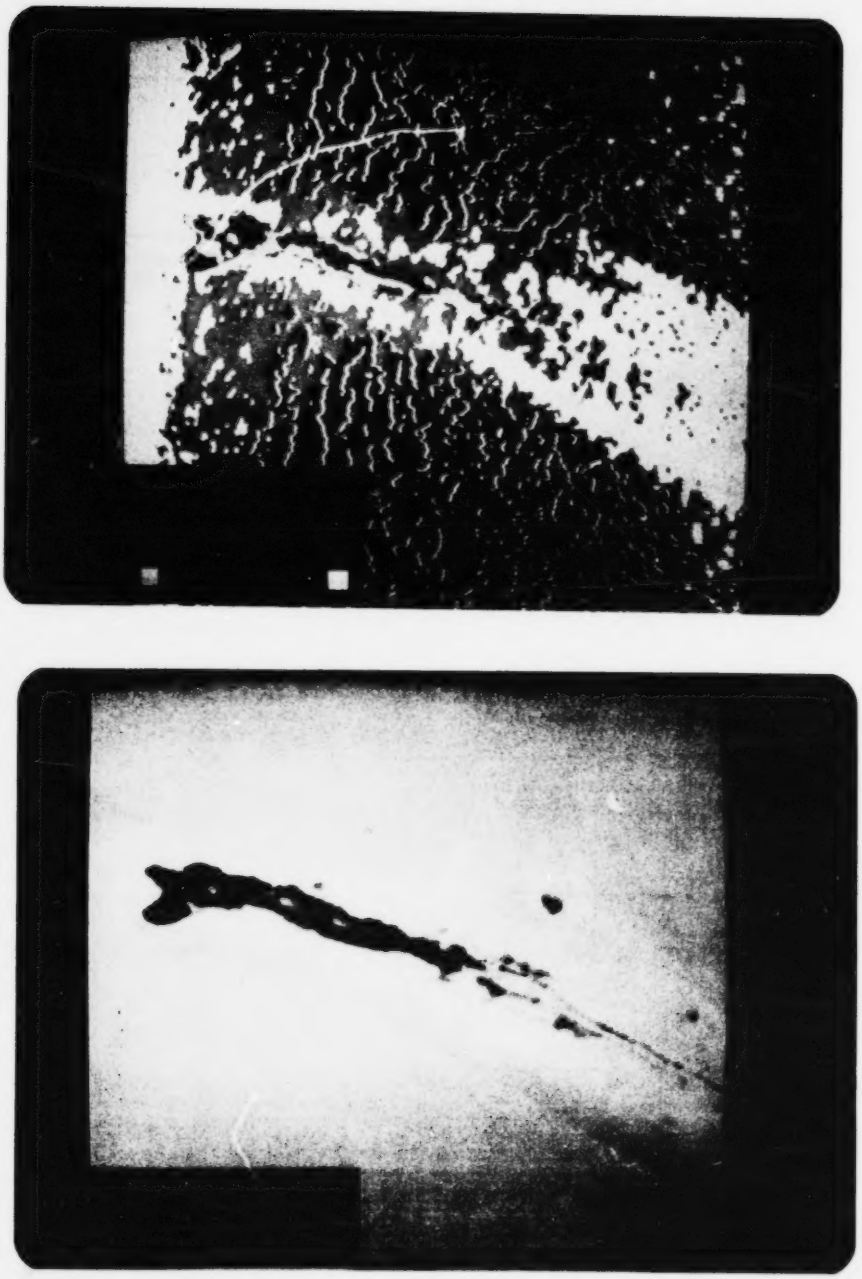

Figure 2.17. Thematic representation and two-channel video sub-scene, 21 October 1981, Line 82 (test)

Table 2.13. Cluster means and standard deviations, 21 October 1981 — Line 82 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	40.4	17.3	5.39	3.18	333
2	40.1	27.5	5.15	2.85	277
3	27.4	40.7	2.13	1.16	110
4	34.3	40.5	2.25	0.00	96
5	42.8	40.3	3.31	1.26	199

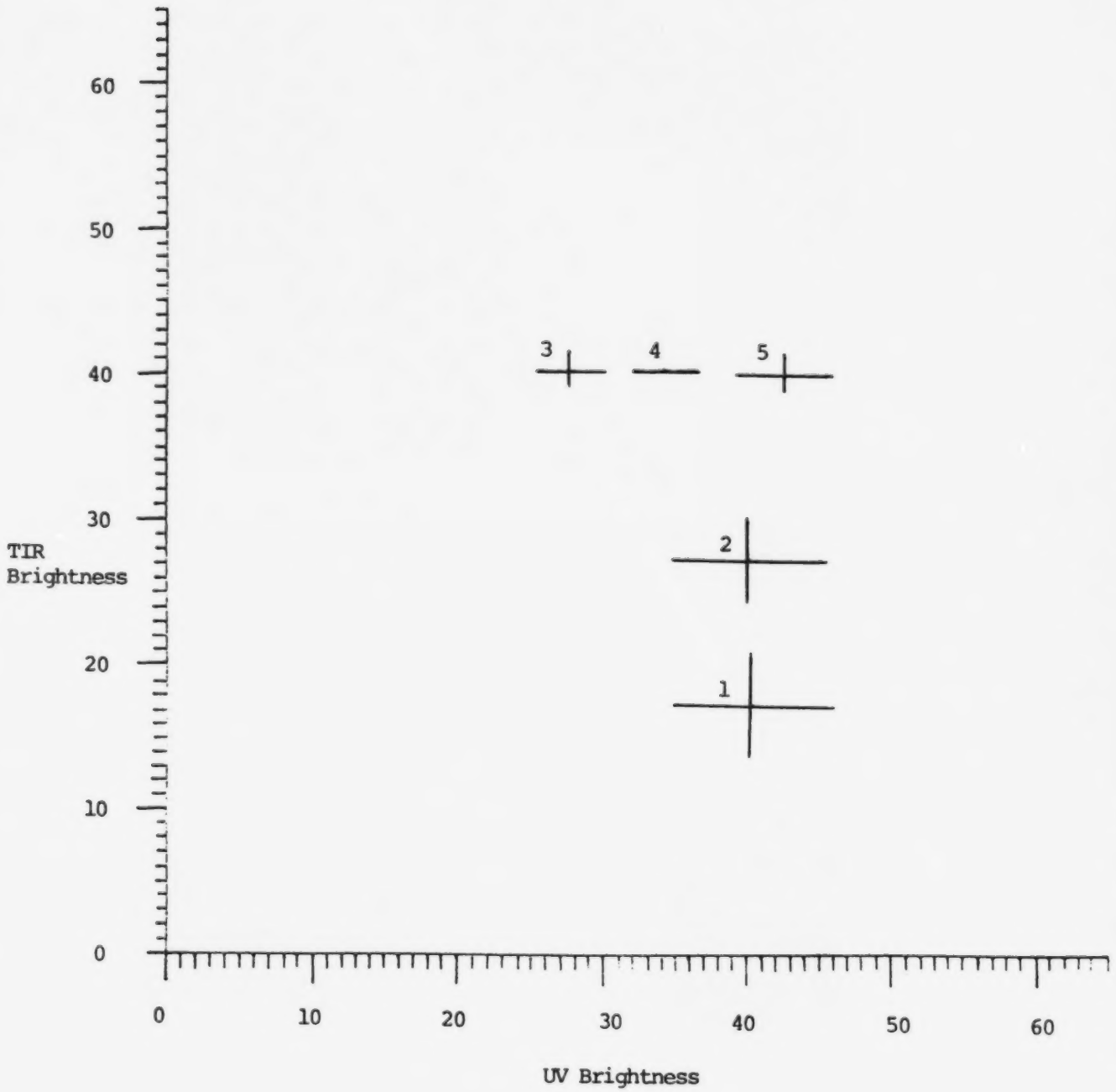

Figure 2.18. Cluster means and standard deviations, 21 October 1981, Line 82 (test)

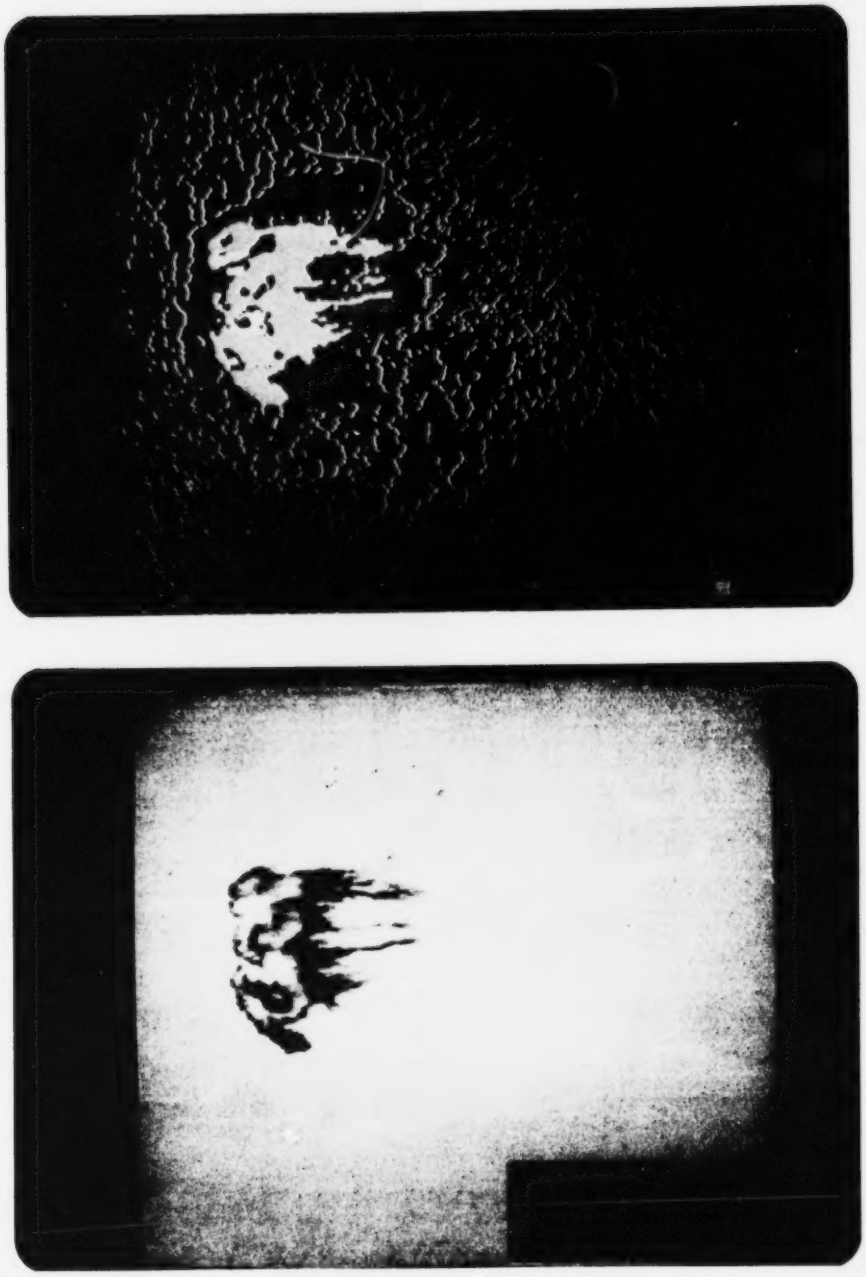

Figure 2.19. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 18 (test)

Table 2.14. Cluster means and standard deviations, 22 October 1981 — Line 18 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	48.5	29.1	5.22	3.46	385
2	32.5	42.7	3.01	0.00	145
3	40.5	42.5	0.00	0.00	136
4	49.8	42.1	3.68	1.66	240
5	49.7	59.3	5.50	4.04	181

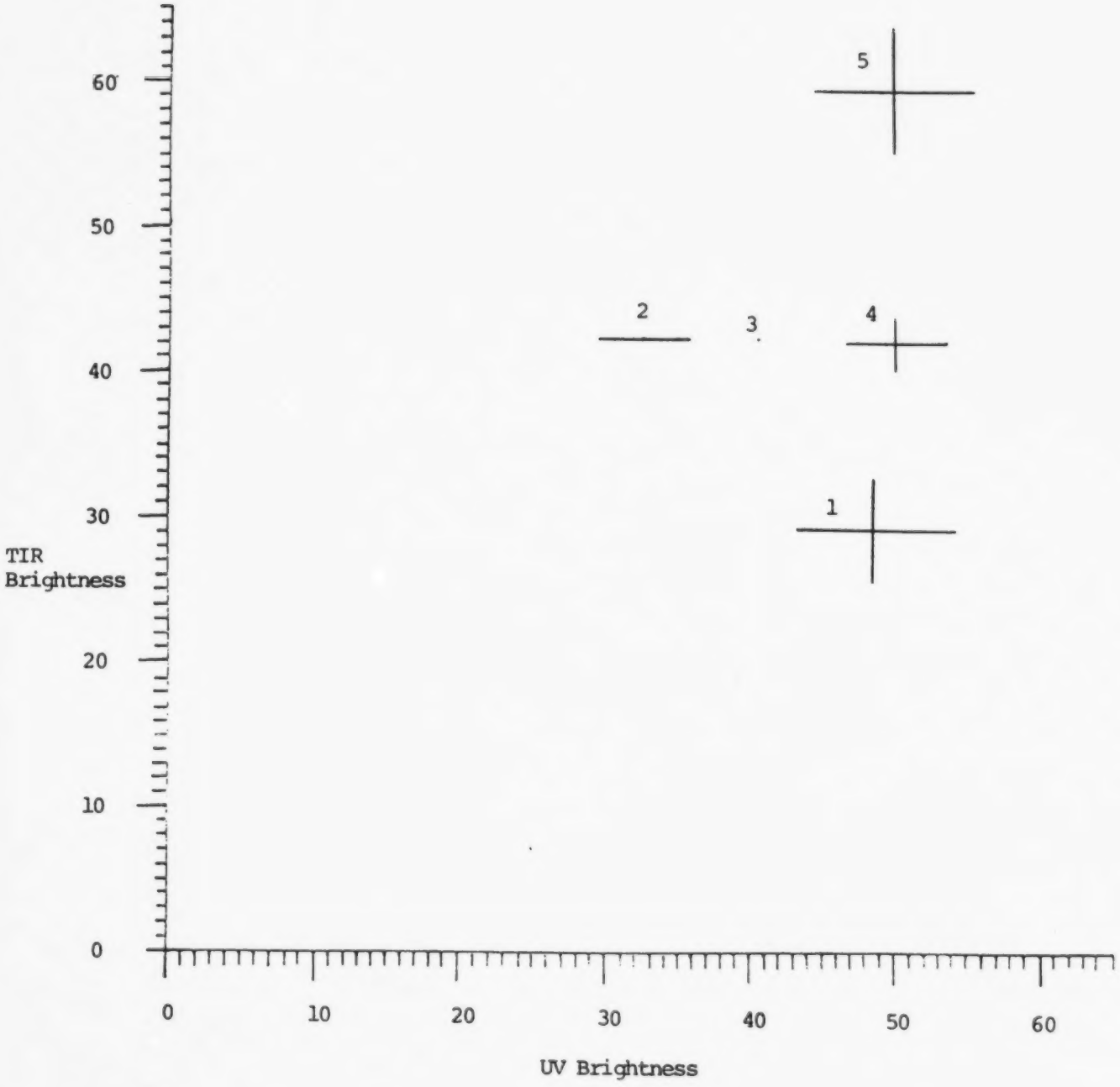

Figure 2.20. Cluster means and standard deviations, 22 October 1981, Line 18 (test)

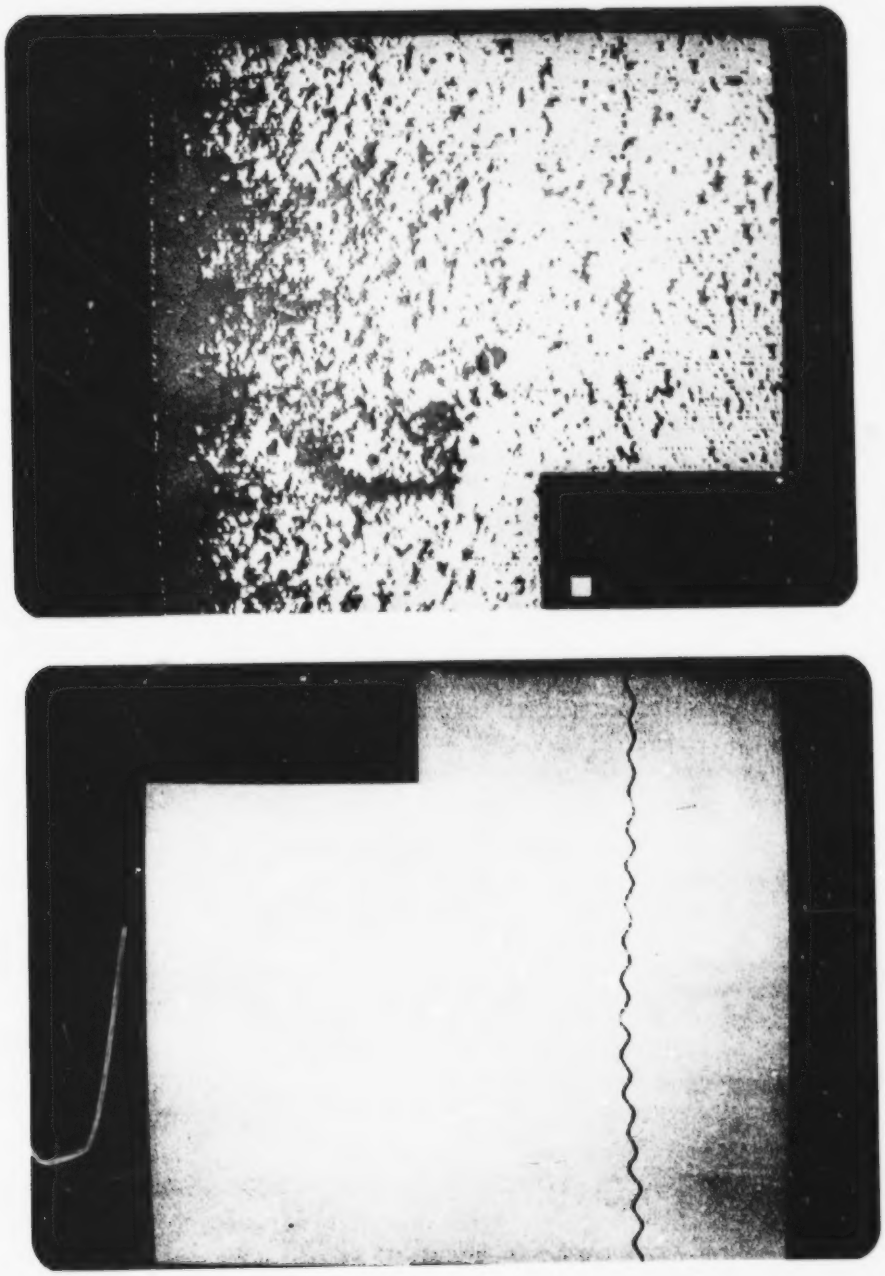

Figure 2.21. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 19 (test)

Table 2.15. Cluster means and standard deviations, 22 October 1981 — Line 19 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	29.4	42.8	3.61	0.00	221
2	39.1	42.5	0.00	0.00	223
3	37.3	58.1	5.18	4.52	177

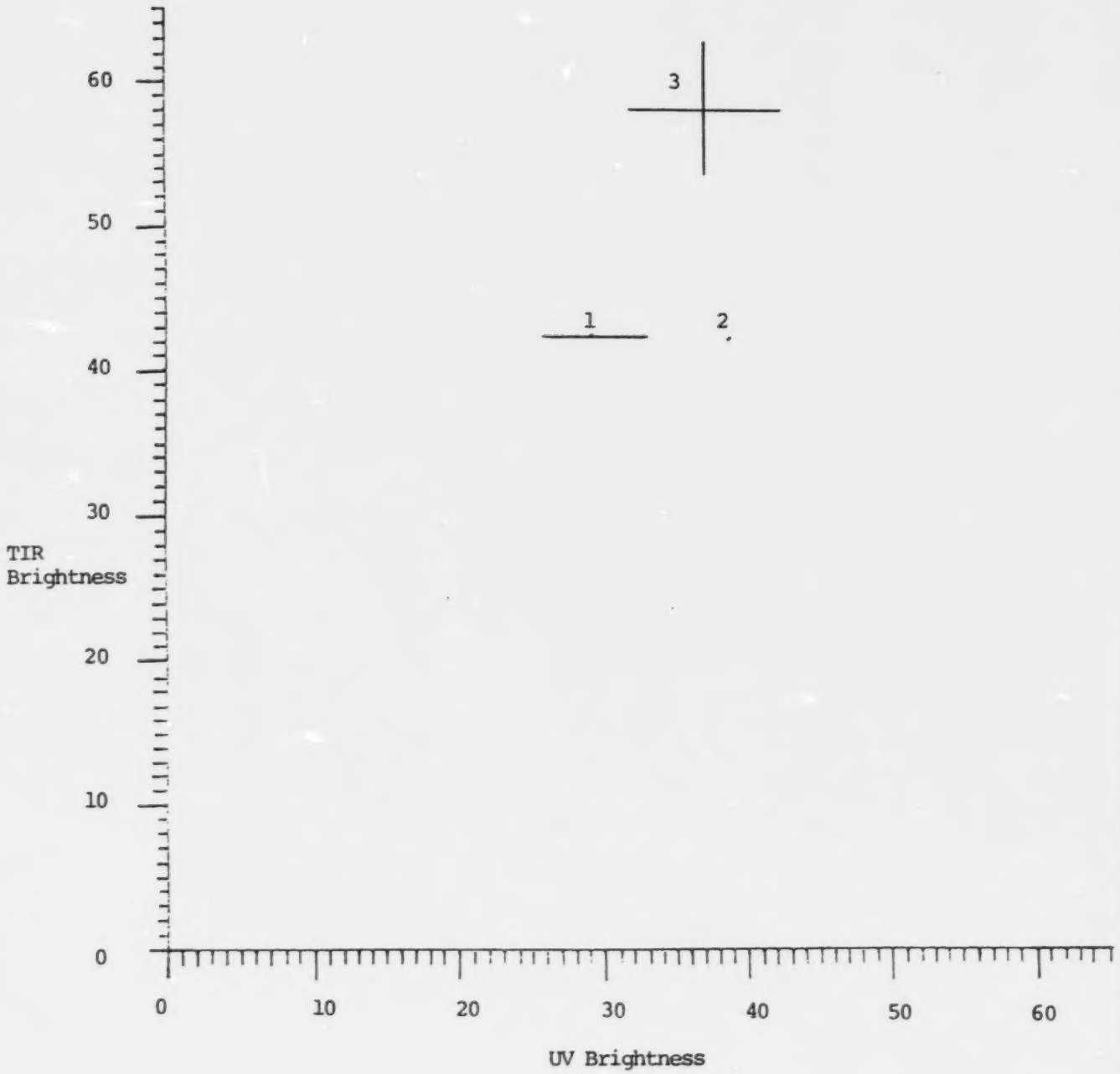

Figure 2.22. Cluster means and standard deviations, 22 October 1981, Line 19 (test)

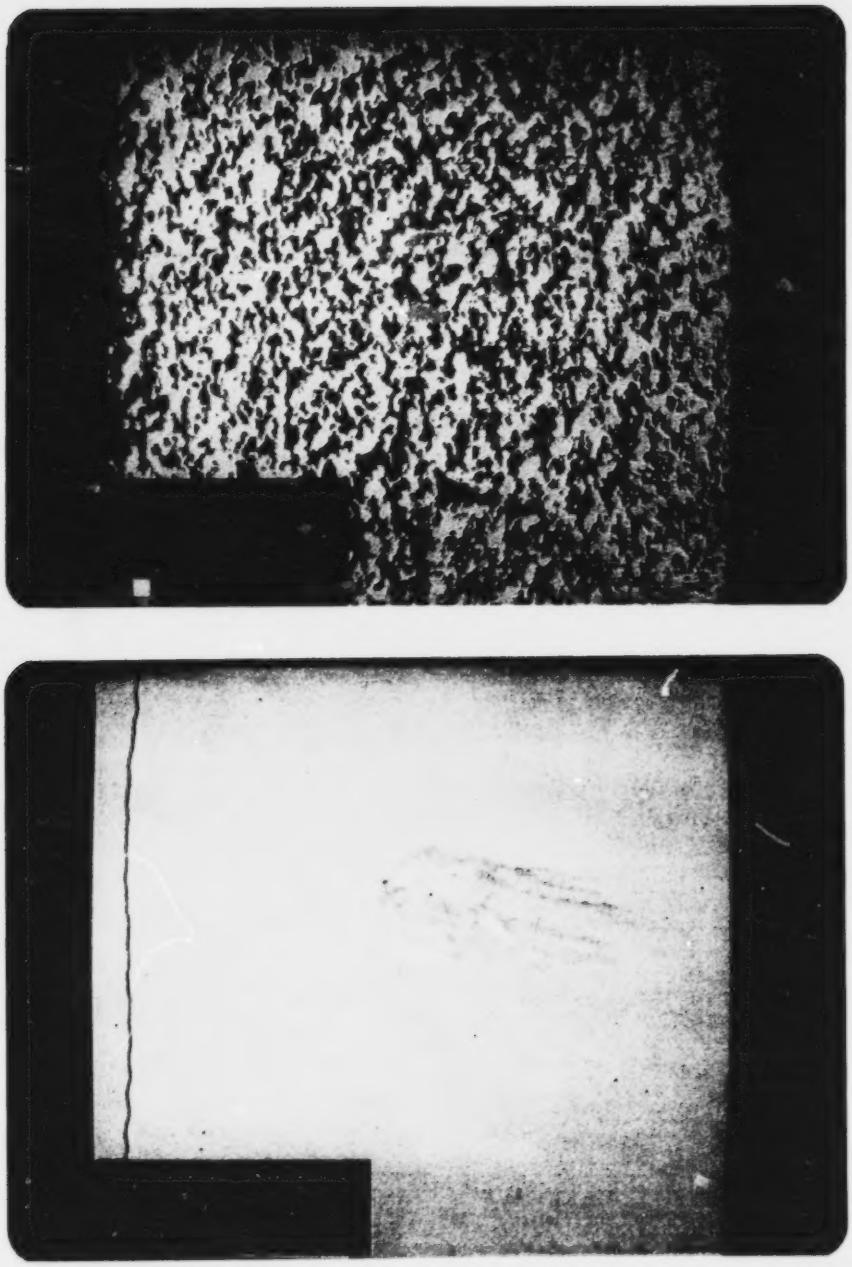

Figure 2.23. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 20 (test)

Table 2.16. Cluster means and standard deviations, 22 October 1981 — Line 20 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	35.4	43.0	1.67	0.00	134
2	28.8	43.1	2.73	0.00	199
3	41.8	42.9	2.50	1.59	229
4	36.2	60.1	5.25	3.67	154

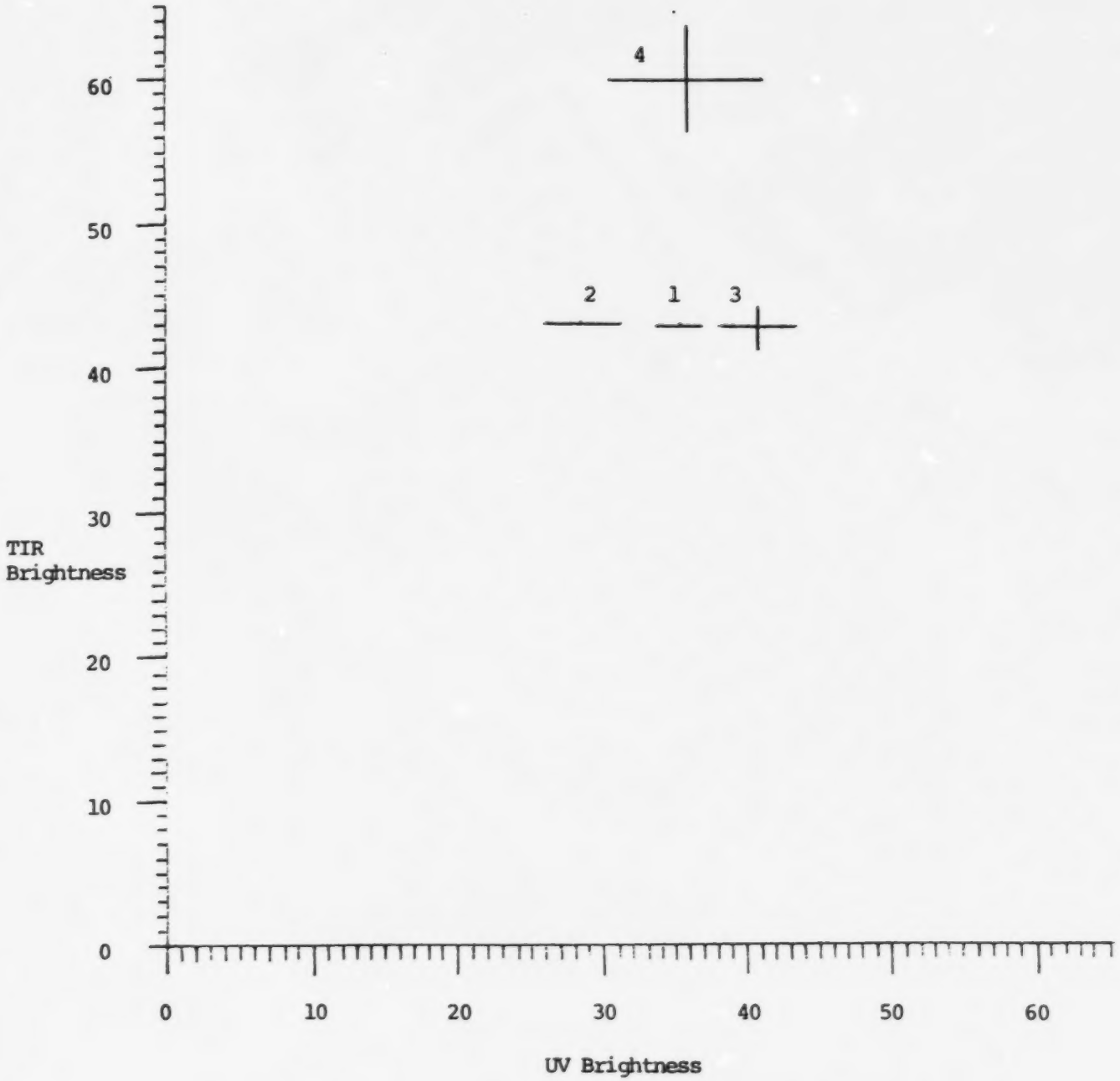

Figure 2.24. Cluster means and standard deviations, 22 October 1981, Line 20 (test)

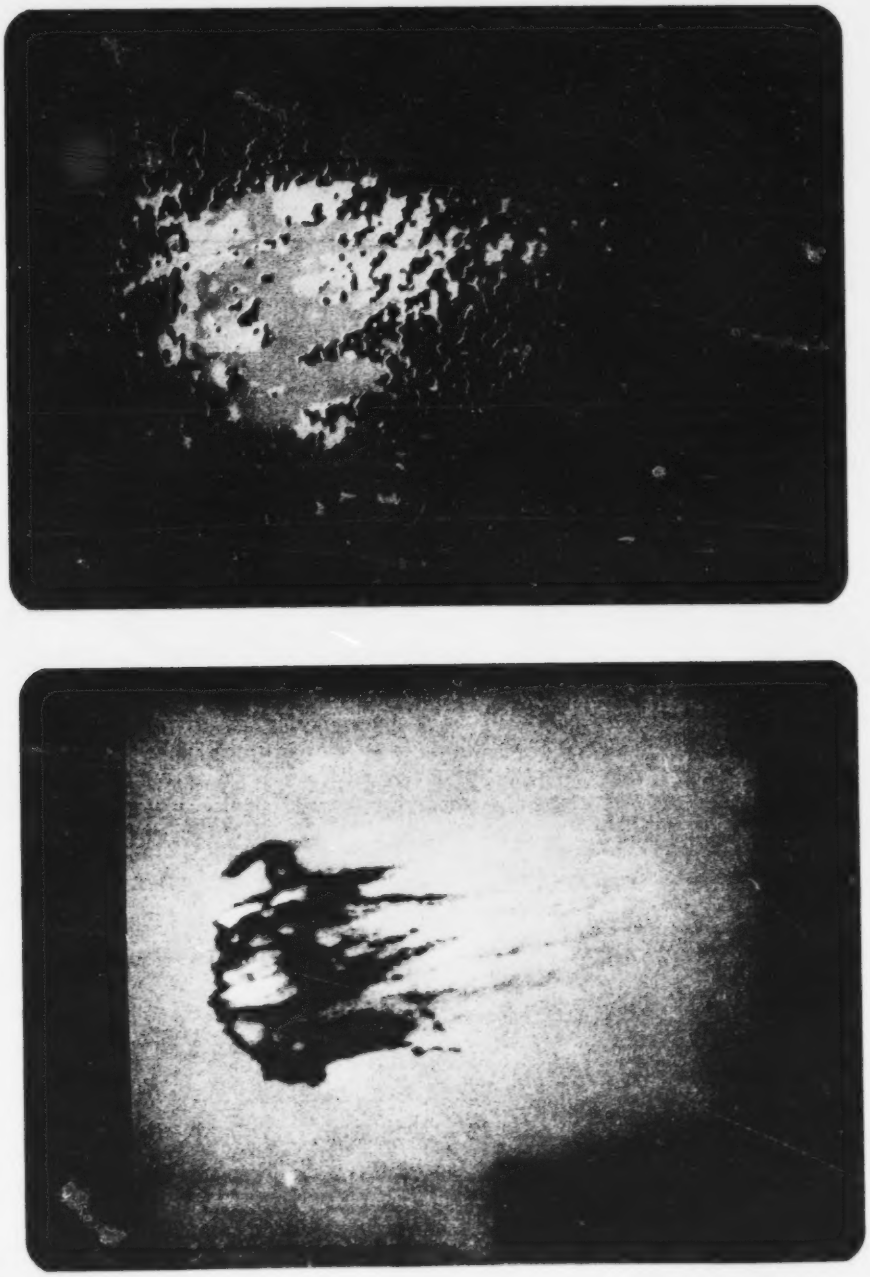

Figure 2.25. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 23 (test)

Table 2.17. Cluster means and standard deviations, 22 October 1981 — Line 23 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	46.5	27.8	5.29	3.73	449
2	28.7	42.1	2.59	1.04	132
3	35.9	41.8	1.97	0.00	124
4	42.6	41.4	1.97	1.53	112
5	50.3	41.0	3.22	2.22	250
6	47.7	58.4	5.82	4.74	182

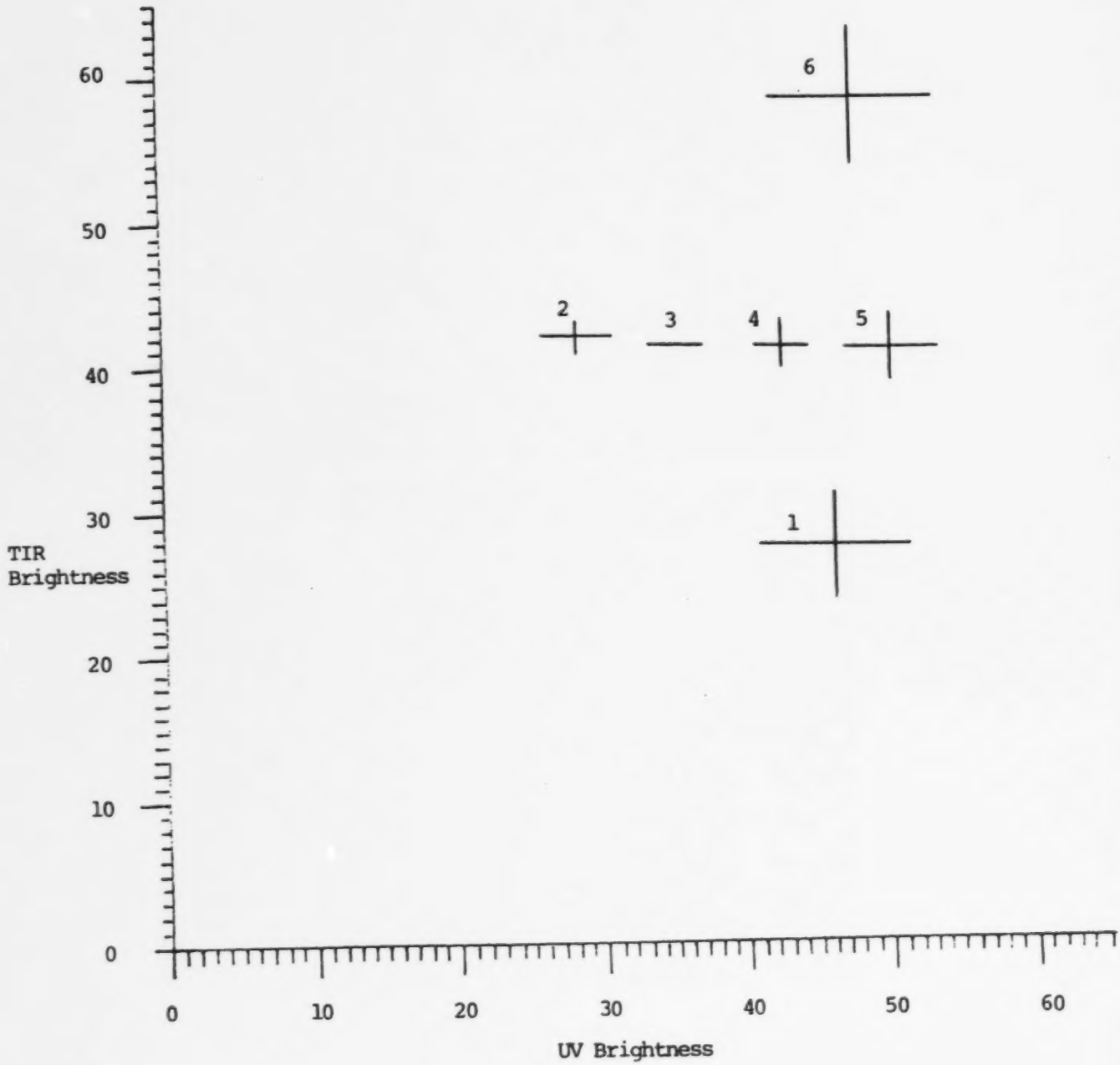

Figure 2.26. Cluster means and standard deviations, 22 October 1981, Line 23 (test)

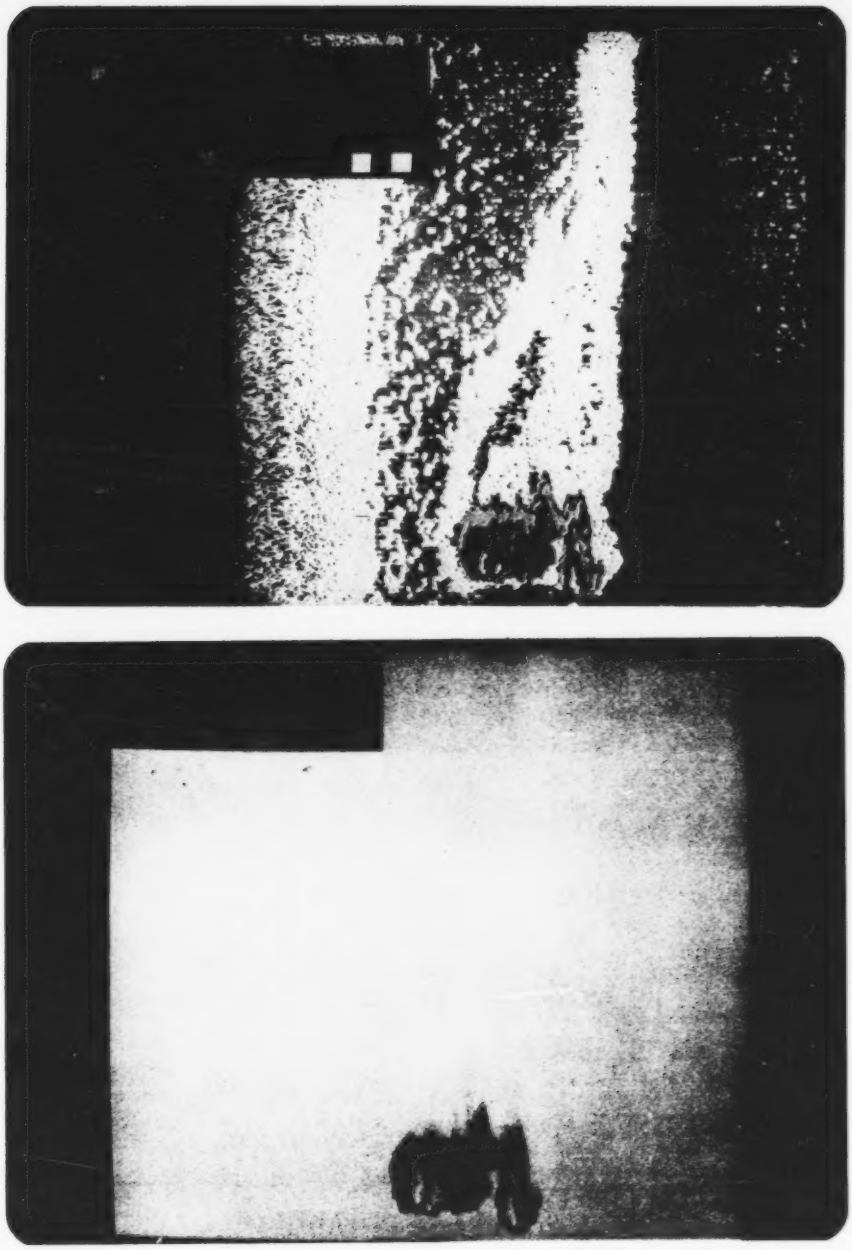

Figure 2.27. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 67 (control)

Table 2.18. Cluster means and standard deviations, 22 October 1981 — Line 67 (control)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	37.3	31.3	1.88	1.57	77
2	37.1	36.0	1.84	1.28	61
3	37.1	41.5	1.77	1.76	60
4	33.3	47.4	1.40	0.00	54
5	41.2	47.0	1.11	0.94	37
6	37.3	47.2	1.11	0.00	45

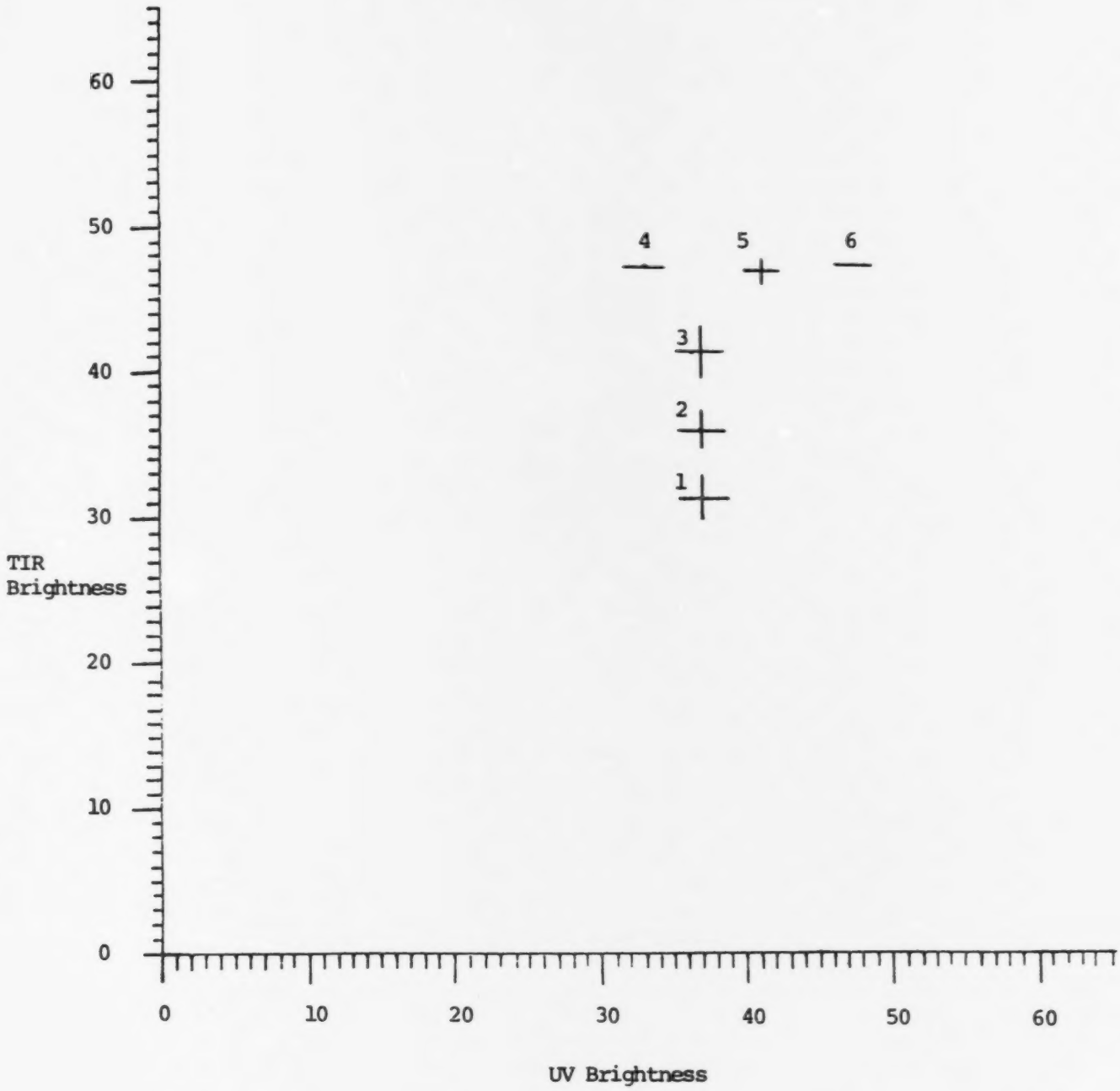

Figure 2.28. Cluster means and standard deviations, 22 October 1981, Line 67 (control)

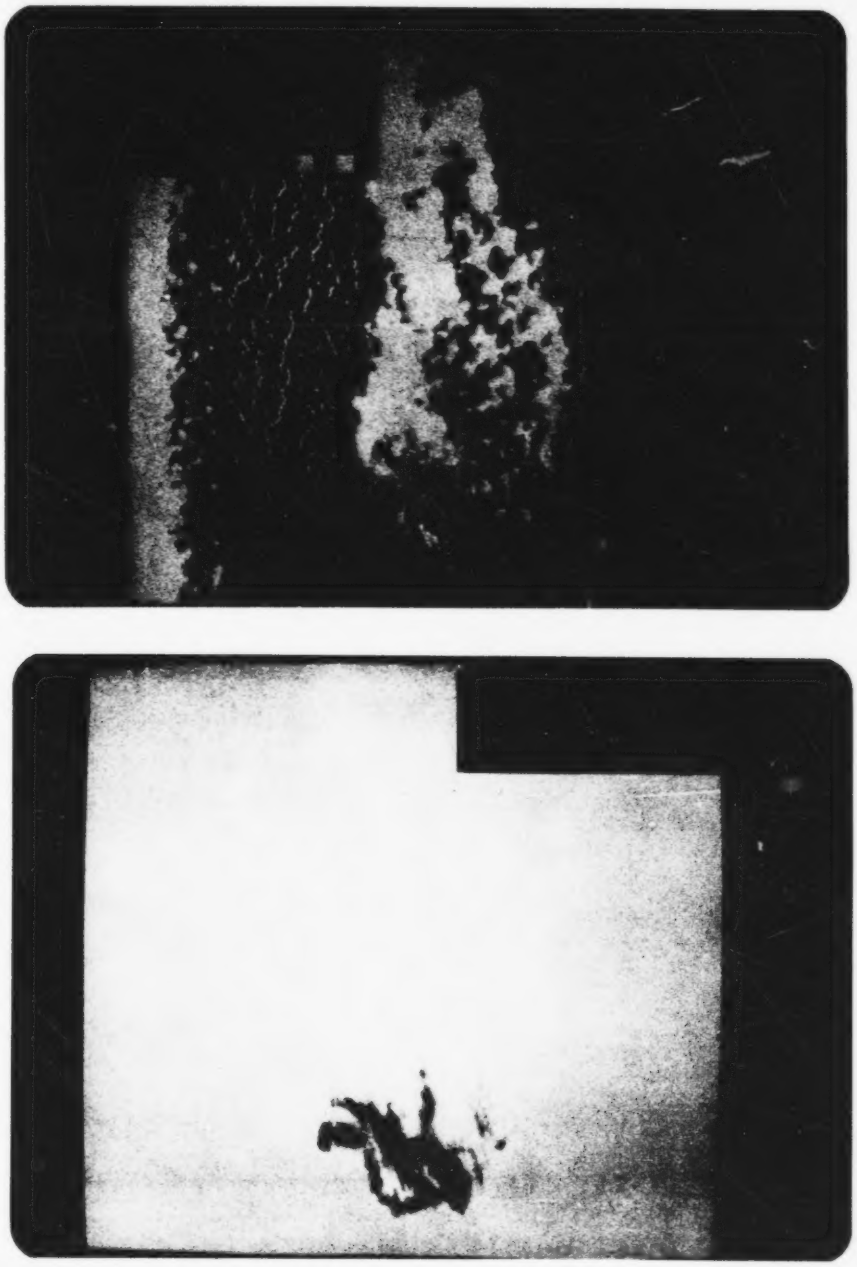

Figure 2.29. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 74 (test)

Table 2.19. Cluster means and standard deviations, 22 October 1981 — Line 74 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	38.3	36.9	2.95	2.13	120
2	38.5	30.8	3.23	2.20	168
3	37.9	46.3	1.41	0.00	55
4	32.6	46.4	2.07	0.00	91
5	43.2	46.3	2.01	0.95	93
6	37.9	59.1	2.87	3.83	73

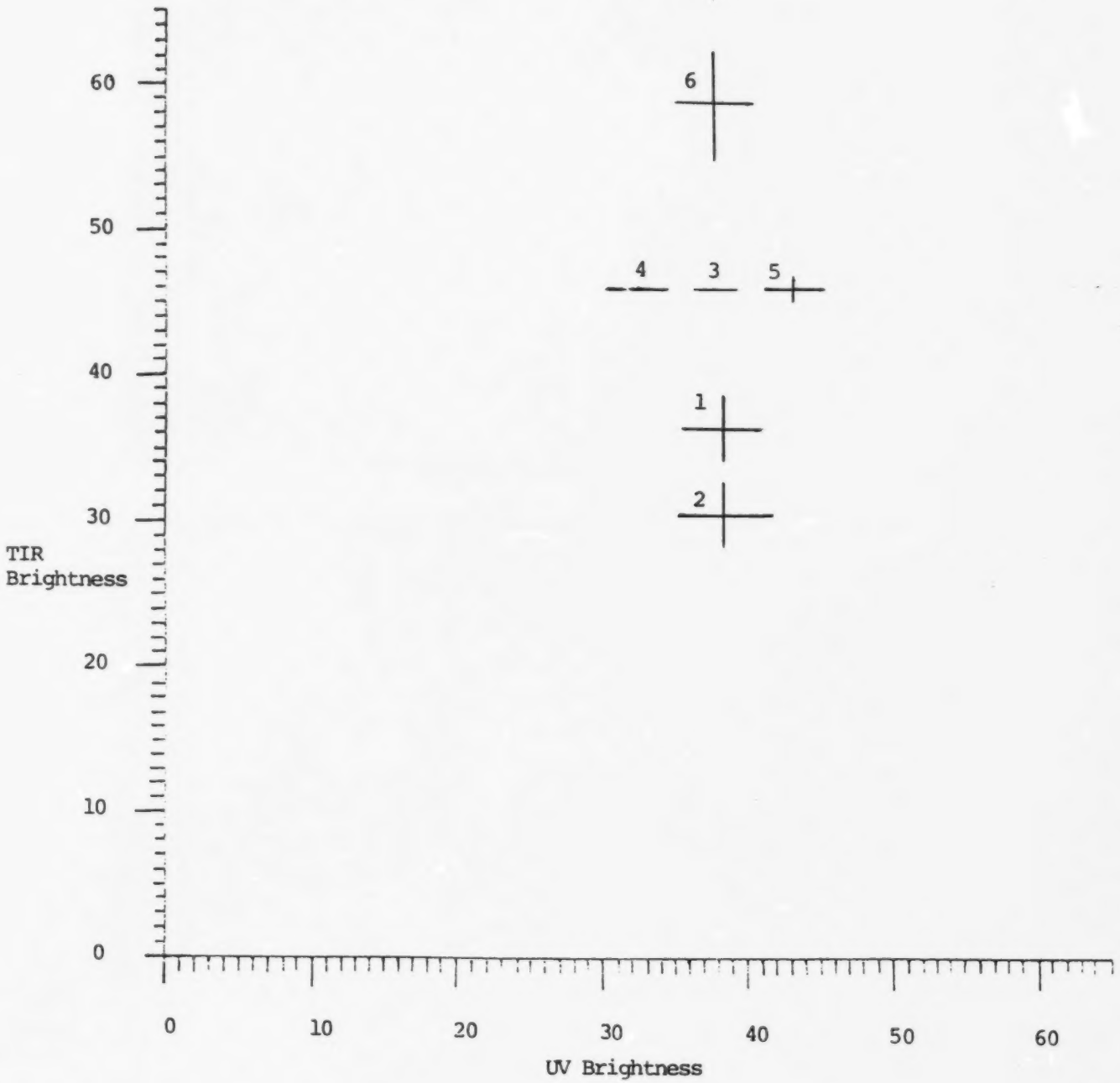

Figure 2.30. Cluster means and standard deviations, 22 October 1981, Line 74 (test)

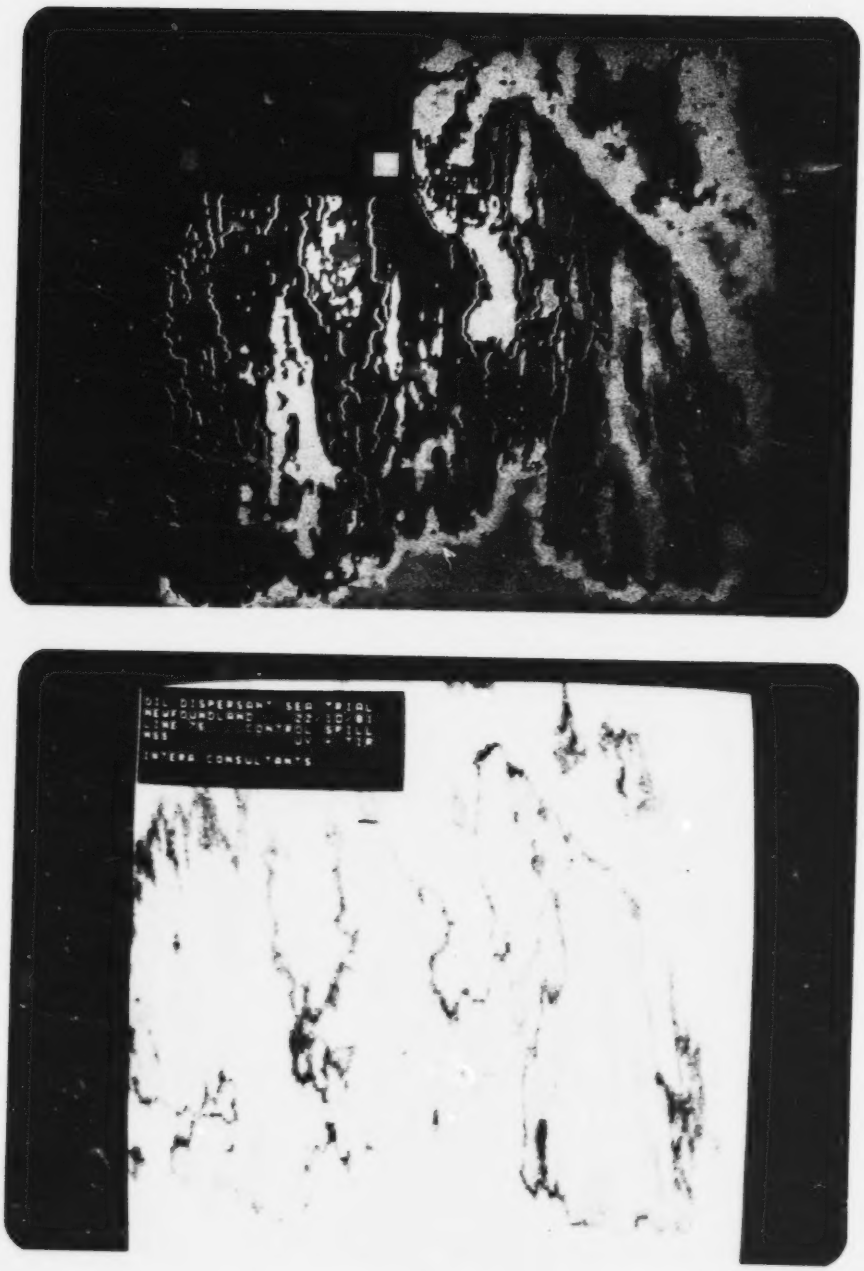

Figure 2.31. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 75 (control)

Table 2.20. Cluster means and standard deviations, 22 October 1981 — Line 75 (control)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	37.6	44.3	2.73	2.80	195
2	43.4	35.6	0.00	2.36	158
3	45.7	28.2	4.04	3.19	312
4	49.6	44.1	2.71	2.59	197
5	43.6	46.8	1.99	2.84	221

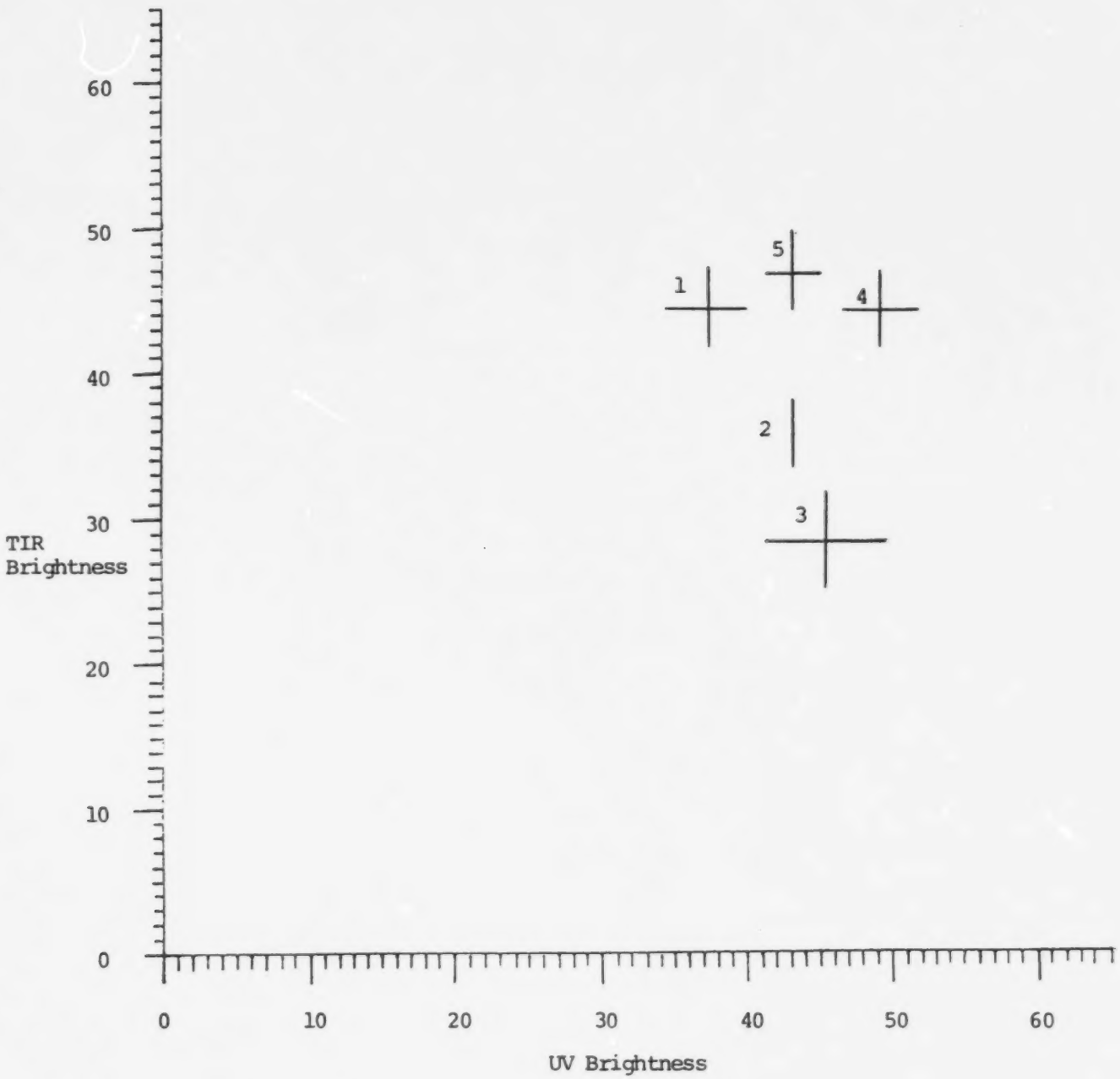

Figure 2.32. Cluster means and standard deviations, 22 October 1981, Line 75 (control)

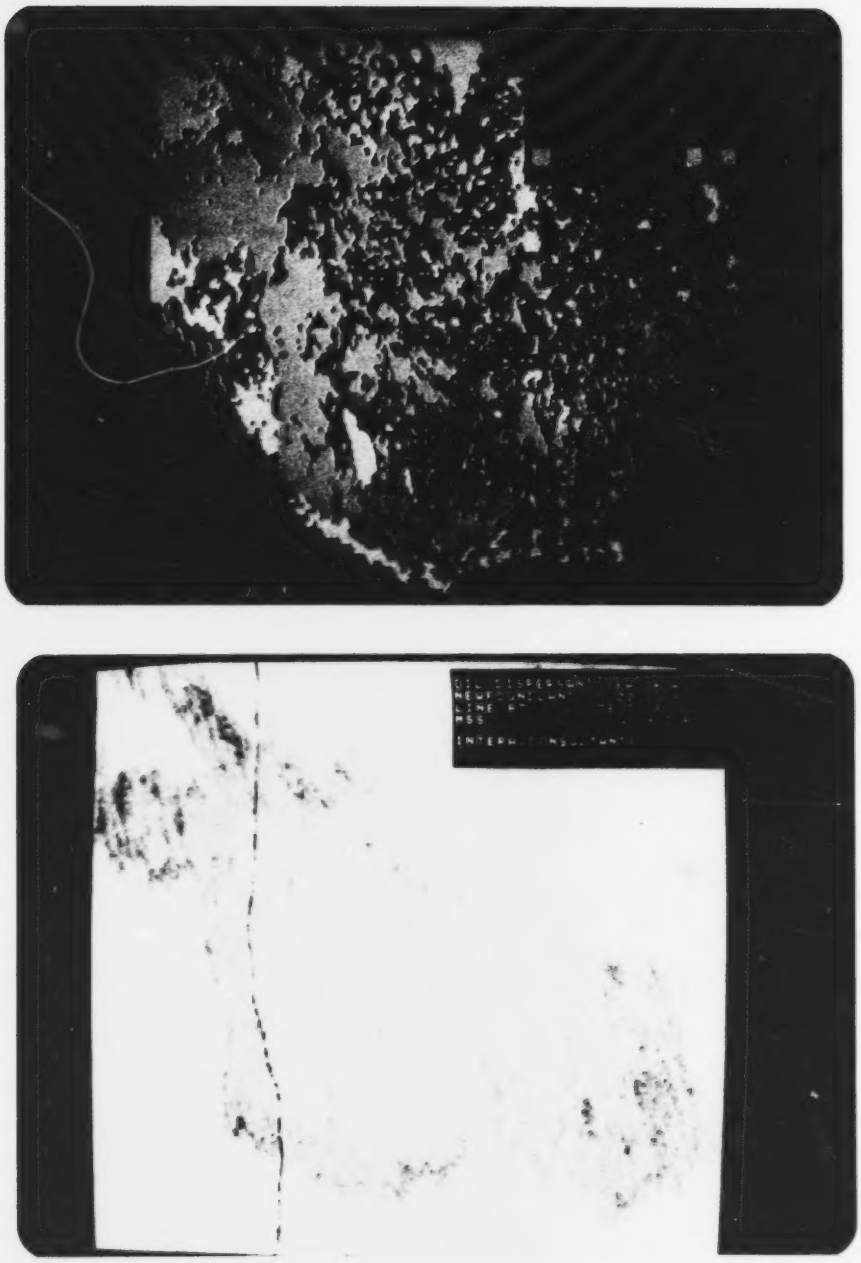

Figure 2.33. Thematic representation and two-channel video sub-scene, 22 October 1981, Line 87 (test)

Table 2.21. Control means and standard deviations, 22 October 1981 -- Line 87 (test)

Theme	Mean UV	Mean TIR	SD UV	SD TIR	Number of Vectors
1	41.9	31.1	2.98	1.94	193
2	41.4	35.9	1.89	1.37	35
3	35.4	38.4	2.23	2.23	138
4	41.8	40.7	1.88	1.32	89
5	46.9	38.4	1.95	2.38	148
6	40.2	56.7	3.11	4.49	149

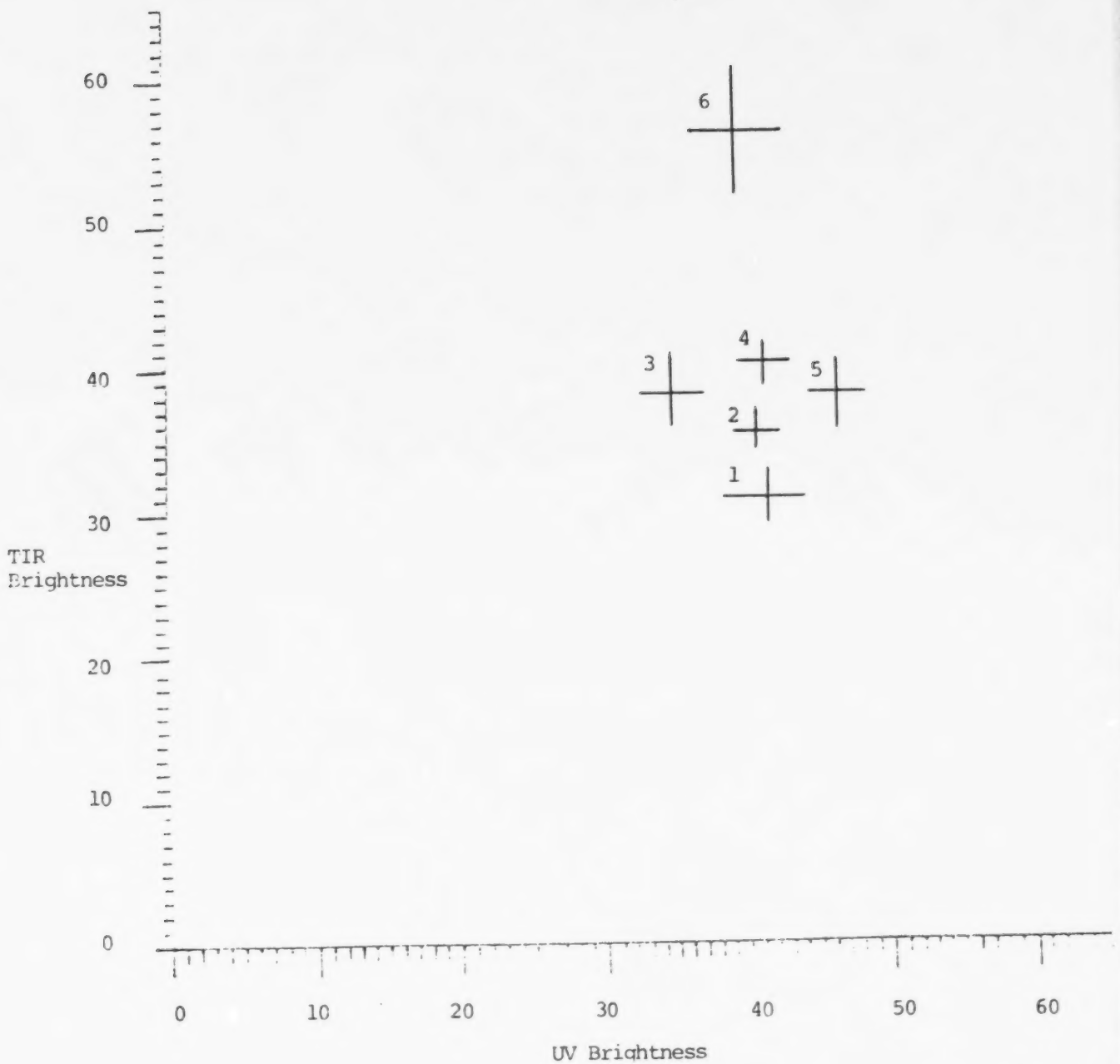

Figure 2.34. Cluster means and standard deviations, 22 October 1981, Line 87 (test)

3. OIL-SLICK MOVEMENT

Oil slick movement is influenced primarily by currents and winds, and spreading is due to forces of gravity and surface tension. The Newfoundland sea trials have been monitored with methods suitable for measuring these parameters.

3.1 TRAJECTORY OF SLICKS

The trajectory of the slicks was monitored by the Canadian Coast Guard (CCG). Spotter aircraft noted the location of the two sampling vessels within their respective slicks. The range and bearing of the sampling vessels from the Gilbert were determined using a radar and pelorus. The range and bearing of a stationary marker buoy and the time were also recorded. The oil-spill trajectory data were provided by Dr S.D. Gill of the CCG (see Tables 3.1 and 3.2, and Figure 3.1). This method of plotting was more satisfactory than using the C-GRSB inertial navigation system (INS) data because:

1. The position of the Gilbert had been used to update the INS and should, therefore, be more accurate.

2. The position of the oil spill was difficult to calculate via aircraft sensor and INS data, especially at low altitudes where the sensors imaged very small areas of the slick.

3. The INS was subject to non-linear drifting over time.

The INS, however, is suitable for tracking an oil spill when approximately 1 nmi precision is adequate. (During this experiment, the INS was instrumental in locating the first day's spills on the second day, as predicted by M. Hirt of Meteorological and Environmental Planning [MEP], using the MEP oil prediction spill model.)

Table 3.1. Spill trajectories, 21 October 1981

Date 21/10/81

GMT	Control Spill		Test Spill	
	Latitude	Longitude	Latitude	Longitude
13:00	47:58.8	52:26.9	---	---
13:24	47:58.8	52:26.1	47:59.8	52:26.5
14:00	47:58.4	52:25.6	47:59.3	52:25.6
14:24	47:58.2	52:25.2	47:58.9	52:25.3
15:00	47:57.9	52:25.1	47:58.6	52:24.0
15:24	47:57.7	52:24.4	47:58.3	52:23.7
16:00	47:57.1	52:23.9	47:58.0	52:23.9
16:24	47:56.7	52:23.8	47:57.7	52:24.0
17:06	---	---	47:57.8	52:23.8

Table 3.2. Spill trajectories, 22 October 1981

Date: 22/10/81

GMT	Control Spill		Test Spill	
	Latitude	Longitude	Latitude	Longitude
12:48	47:59.8	52:29.2	---	---
13:24	47:59.9	52:29.0	48:01.0	52:29.7
14:00	47:59.9	52:29.0	48:01.0	52:29.6
14:24	47:59.9	52:29.0	48:01.3	52:29.5
15:00	48:00.2	52:28.6	48:01.4	52:29.3
15:24	48:00.1	52:28.5	48:01.4	52:29.3
16:00	48:00.5	52:28.0	48:01.5	52:29.0
16:48	48:00.7	52:27.8	48:01.6	52:28.7

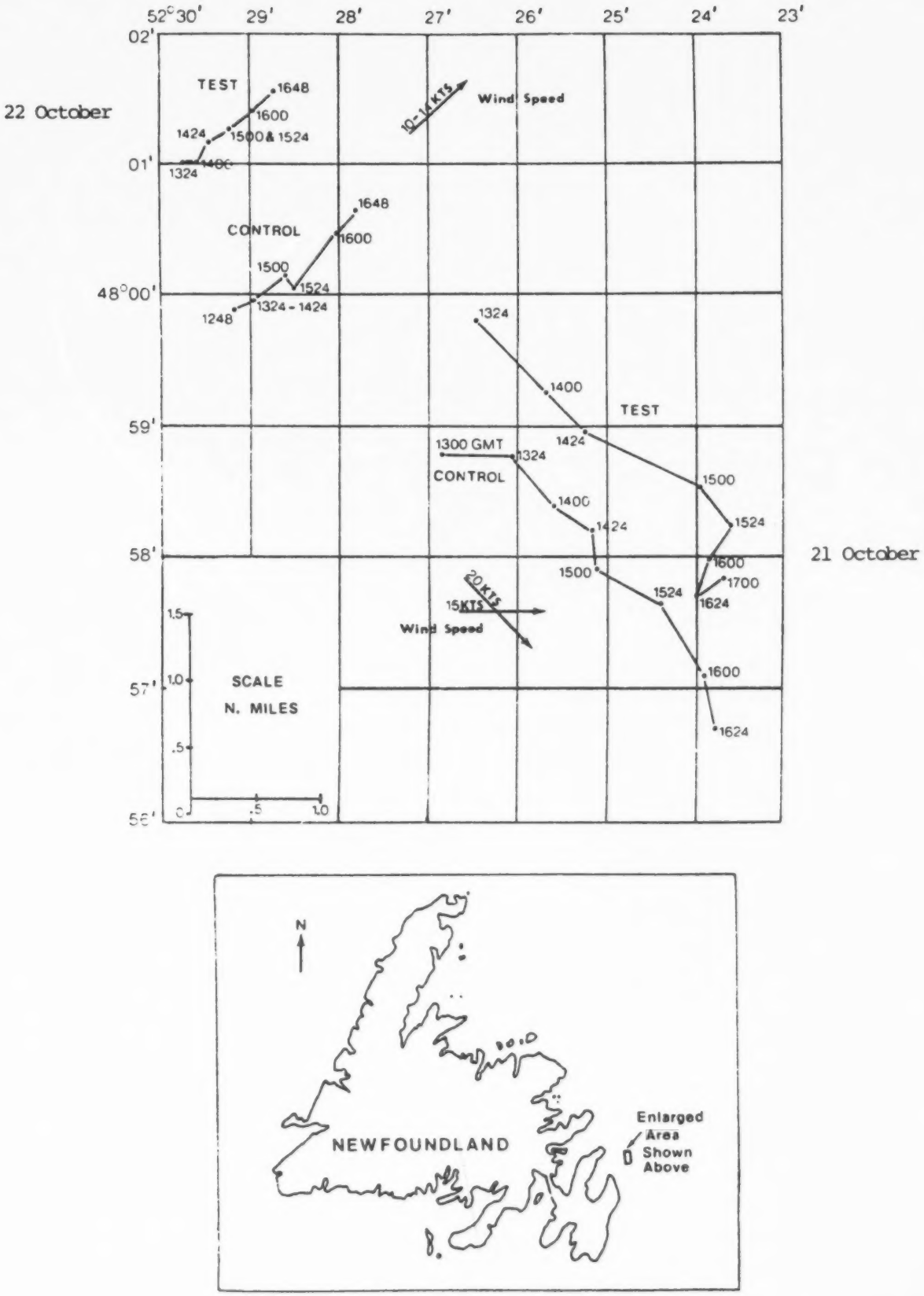

Figure 3.1. Plotted spill trajectories; 21 October 1981 (lower right) and 22 October 1981 (upper left). (Data courtesy CCG.)

3.2 AREAL EXTENT HISTORY OF SLICKS

The areal extent of the oil slicks has been measured, using the available RC-10 photography because of its minimal geometric distortion. The spread rate of this type of oil, with and without added dispersant under specific environmental conditions, may be examined readily.

Problems encountered during the discharging of the oil on 21 October caused the control spill to be very large. As a result, photography showing the entire spill area was available only for 22 October.

The slick area was interpreted visually and traced to acetate. The area of the slick was determined, using a dot-grid planimeter, and correlated to time from start of spill (see Table 3.3 and Figure 3.2). It is interesting to note that the spread of both control and test spills was very similar, despite application of dispersant to the test spill only. The apparent difference in spread rate between test and control spills after approximately 150 min might have been due to area interpretation problems, caused by intrusion of the slick into the specular reflectance region of the photography.

Table 3.3. Areal extent history of spills, 22 October 1981

	Control	Test
Start of Spill (GMT)	12:29	12:53
Dispersant Added	---	13:12

Line	Spill	Time Since Spill (min)	Area (1000 m^2)
11	Control	20	18.9
12	Control	23	23.0
14	Control	28	31.4
14	Test	4	1.8
15	Test	6	2.7
16	Control	33	40.9
16	Test	10	6.3
17	Test	13	8.5
18	Test	16	12.8
23	Test	31	33.7
24	Control	59	64.3
24	Test	35	29.6
35	Test	76	75.3
45	Test	104	113.8
47	Test	110	122.7
48	Control	139	128.6
49	Test	118	105.5
50	Control	147	118.8
51	Test	126	124.2
57	Control	168	132.4
58	Test	146	132.9
60	Test	153	146.9
62	Test	160	180.3
63	Control	187	134.1
64	Test	167	187.6
65	Control	194	145.5
66	Test	173	235.5
67	Control	201	161.6
68	Test	182	208.1

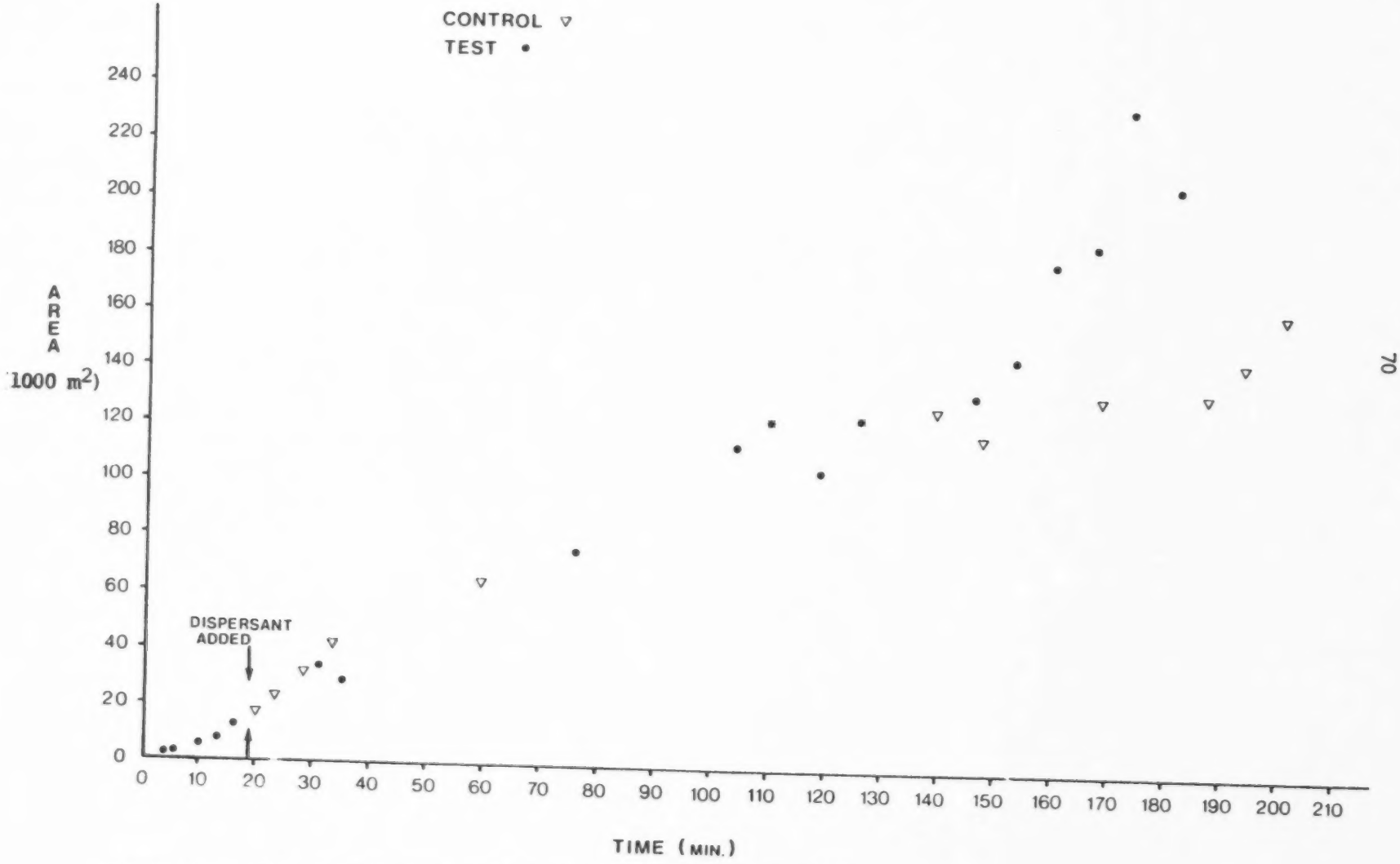

Figure 3.2. Time versus areal extent of spills, 22 October 1981

4. SKY RADIANCE MEASUREMENT

The sky radiance detector was used to measure the downwelling radiance in the UV region of the spectrum. The different altitudes from which data were collected permitted an assessment of the relationship between downwelling (sky) radiance and atmospheric attenuation. As the sky radiance data were collected over a span of time, sun elevation angle changes were to be considered.

The raw values of the sky radiance detector readings in Watts were first calibrated for spectral sensitivity and field of view (FOV) restrictions. The resulting units were $Wcm^{-2}sr^{-1}nm^{-1}$ (INTERA, 1982). A further correction was applied for solar elevation angle, to normalize recorded intensities to a zenith illumination angle.

$$I_o = I_1/\cos\theta$$

where θ = solar zenith angle

I_1 = recorded spectral radiance for sun zenith angle θ

I_o = normalized radiance

The resulting relationship between zenith sky illumination intensity and altitude is listed in Table 4.1 and graphically illustrated in Figure 4.1. The low correlation (-.4647 for 21 October and -.3331 for 22 October) between these two variables probably is due to the very small range of atmospheric path lengths experienced in these flights, and possibly to thin cirrus clouds.

Table 4.1. Normalized spectral radiance and altitude, 21 October 1981

Spectral radiance units = $Wcm^{-2}sr^{-1}nm^{-1}$

GMT	Altitude (ft)	Normalized Sky UV Spectral Radiance x 10^{-6}
1213	990	20.35
1217	980	17.91
1222	1070	18.03
1226	1030	17.63
1230	1060	17.95
1233	1080	17.41
1235	1080	17.60
1238	1080	17.08
1240	1060	17.38
1250	1250	17.04
1255	1230	17.45
1258	1250	16.92
1301	1230	17.09
1330	1240	16.61
1335	1240	16.52
1338	1240	17.14
1340	1240	16.36
1345	1300	16.65
1348	1380	16.76
1400	1290	16.42
1404	1300	16.13
1409	1260	15.92
1414	1260	16.36
1419	1270	16.36
1423	1270	16.90
1427	1190	16.36
1431	1280	16.58
1449	1230	16.15
1454	3000	16.15
1458	3100	15.25
1512	3450	15.36
1517	3400	15.26
1520	3400	15.19
1535	550	16.50
1538	570	16.33
1541	560	16.40

continued . . .

Table 4.1. Concluded

GMT	Altitude (ft)	Normalized Sky UV Spectral Radiance x 10^{-6}
1545	540	16.23
1552	570	16.23
1555	570	16.32
1600	550	17.45
1604	580	16.15
1606	550	15.98
1609	590	15.98
1625	1400	16.90
1628	1450	16.98
1637	1470	16.87
1641	1230	16.69
1645	1010	17.23
1650	1030	17.15
1654	1040	16.76
1659	1050	16.85
1712	5000	16.08
1718	5000	16.27
1722	5000	14.86

Table 4.2. Normalized spectral radiance and altitude, 22 October 1981

Spectral radiance units = $Wcm^{-2}sr^{-1}nm^{-1}$

GMT	Altitude (ft)	Normalized Sky UV Spectral Radiance x 10^{-6}
1233	540	18.42
1238	540	19.06
1242	460	20.17
1245	510	19.19
1247	480	19.19
1249	1200	19.19
1252	1170	18.63
1254	1200	18.63
1257	1220	18.73
1302	1200	19.66
1313	1110	18.72
1317	1170	19.26
1320	1170	19.14
1323	1170	18.45
1334	610	19.01
1337	600	19.11
1341	590	19.52
1345	580	18.57
1352	460	19.36
1401	1060	19.20
1410	1450	19.20
1412	1330	18.83
1415	1400	19.49
1432	1390	18.54
1437	1450	19.08
1443	1560	19.88
1448	2190	18.87
1451	2030	19.67
1456	2030	19.47
1459	2040	19.57
1526	2200	19.47
1530	2380	18.43
1533	2500	19.12
1536	2300	18.60
1540	2300	18.95

continued . . .

Table 4.2. Concluded

GMT	Altitude (ft)	Normalized Sky UV Spectral Radiance x 10^{-6}
1543	2300	19.75
1546	2400	19.05
1558	2500	19.49
1602	2400	18.44
1606	2400	19.08
1612	2450	18.98
1615	2450	19.34
1620	470	19.34
1627	490	22.38
1629	460	20.31
1631	450	22.83
1634	450	23.30
1638	480	22.94
1641	480	24.18
1645	520	22.62
1647	490	22.81
1649	530	23.49
1651	400	24.64
1658	2010	22.20
1700	2100	25.00
1702	1850	21.10

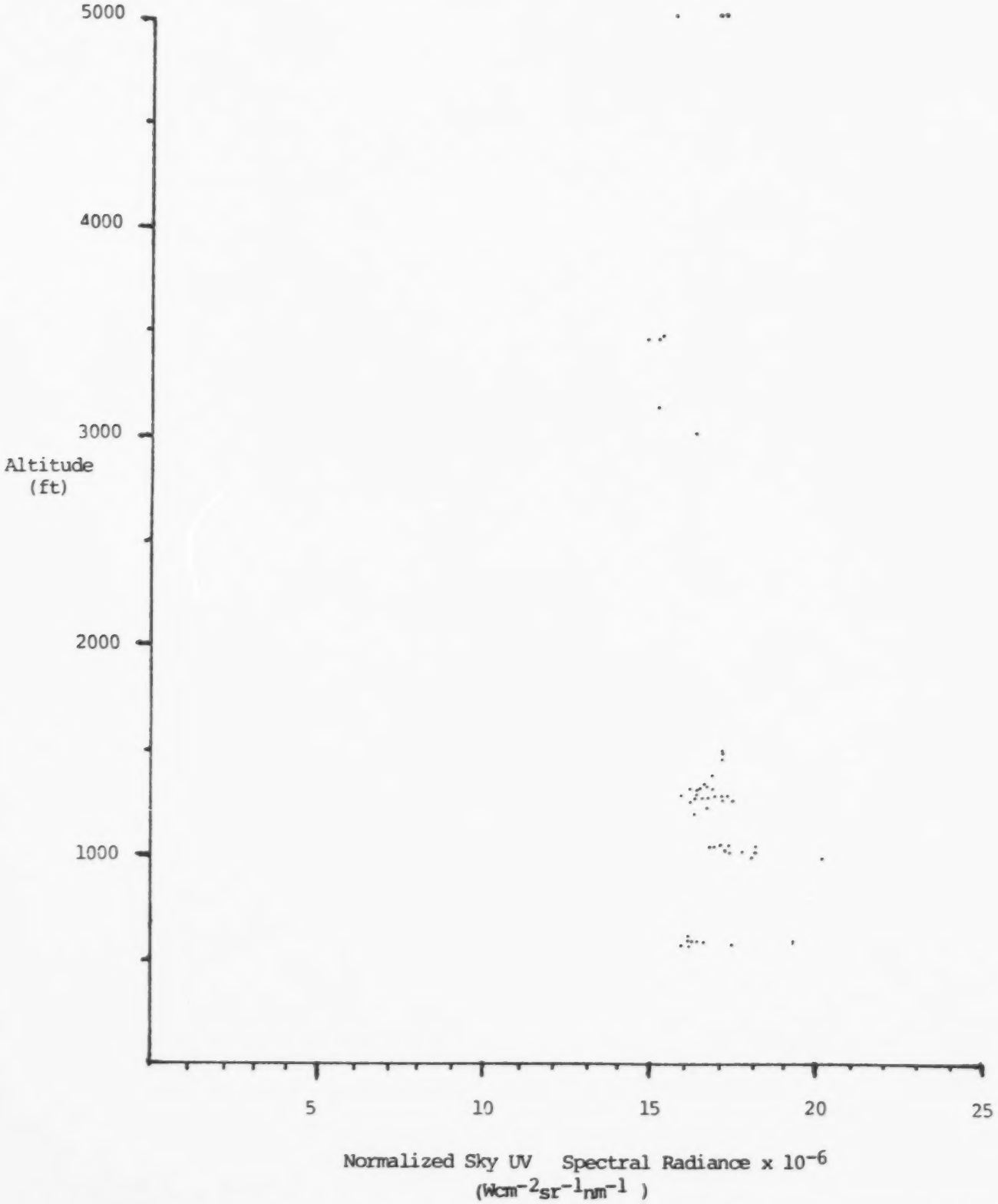

Figure 4.1. Plot of altitude versus normalized spectral radiance, 21 October 1981

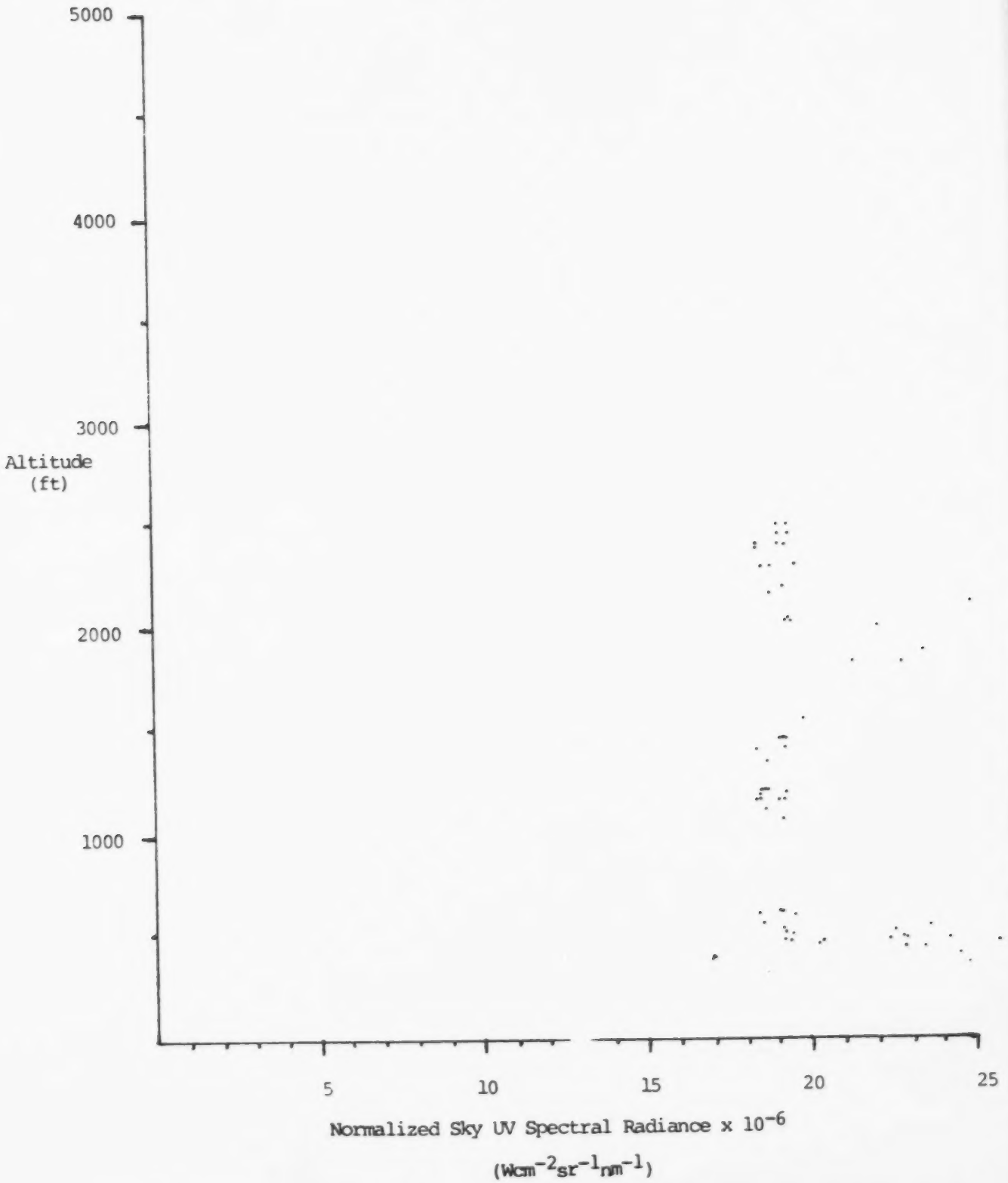

Figure 4.2. Plot of altitude versus normalized spectral radiance, 22 October 1981

5. RECOMMENDATIONS

1. The *in situ* data collected of oil thickness variability should be used to study the UV reflectance and TIR emission characteristics of oil, as a function of oil layer thickness.

2. A study should be conducted on the mechanisms contributing to the variations observed in the apparent temperature of the oil slick.

3. The areal extent history of the slicks on 21 October 1981 should be compiled from areal measurements on MSS digital data, because these are unavailable from the camera data.

4. Oil-water UV contrasts should be calculated for the various regions delineated in the thematic images. To do these calculations, corrected UV dark offset values must be determined for the appropriate flight lines.

5. A study should be conducted to determine whether the oil-water UV contrast is a function of the age of the oil slick.

6. REFERENCES

Gordon, L.A. 1978. Clustering using the migrating means algorithm; CIAS memorandum 78-21. Canada Centre for Remote Sensing, Ottawa, Ontario.

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POOR

QUALITY

ORIGINAL